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Hydro Brake Regulated Storage System for Stormwater Management

Cleveland Dept. of Public Utilities, OH

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Project Officer: Ralph G. Christensen - 312/353-3545, USEPA, Region V
U.S. EPA Technical Advisor: Douglas C. Ammon - 513/684-7871

16. ABSTRACT

This reseach project was initiated with the overall objective of determining the ability of the Hydro Brake flow control device, in conjunction with off-line underground storage, to limit the rate of stormwater flow into combined sewers. The intended result of this control was the reductions of overflows and street and basement flooding during storm events.

Three underground corrugated metal pipe storage tanks were constructed and outfitted with Hydro Brakes of different flow rates. The storage tanks were filled, and their rates of discharge were measured to establish discharge curves for the Hydro Brakes. The Hydro Brakes were then monitored for performance during actual storm events. Homeowner surveys were also undertaken to evaluate the effects of the Hydro Brake/storage installations on flooding.

It was demonstrated that the Hydro Brakes did release storm flows to combined sewers more slowly, and at a rate more nearly independent of head, than orifices of equivalent size. The use of off-line storage tanks appeared to reduce the incidence of street and basement flooding.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concerns about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technologies and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication reflects the application of research, in a project scale demonstration of innovative technology.

In order to support the demonstration of new methods and techniques for the control of pollution within the Great Lakes, Congress provided funds through Section 108 of the Clean Water Act. This project to develop and demonstrate innovative yet practical approaches to solve problems caused by discharges from combined sewers, has been funded by Section 108 through the Great Lakes National Program Office.

The deleterious effects of stormsewer discharges and combined sewer overflows upon the nation's waterways have become of increasing concern in recent times.

This report presents results of a research project that was initiated with the overall objective of determining the ability of the Hydro Brake flow control device, in conjunction with offline underground storage, to limit the rate of stormwater flow into selected combined sewers in the city of Cleveland, Ohio. The intended result of this control was the reduction of overflows and street and basement flooding during storm events.

Francis T. Mayo, Director
Municipal Environmental
Research Laboratory
Cincinnati, Ohio

Madonna F. McGrath, Director
Great Lakes National Program
Office
Chicago, Illinois

ABSTRACT

This research project was initiated with the overall objective of determining the ability of the Hydro Brake flow control device, in conjunction with offline underground storage, to limit the rate of stormwater flow into combined sewers. The intended result of this control was the reductions of overflows (CSO) and street and basement flooding during storm events.

Three underground storage tanks were constructed and outfitted with Hydro Brakes of different flow rates. The storage tanks were filled, and their rates of discharge were measured to establish discharge curves for the Hydro Brakes. The Hydro Brakes were then monitored for performance during actual storm events. During the study, each Hydro Brake was downsized and retested for discharge rates, permitting the evaluation of six sizes of Hydro Brakes. Homeowner surveys were also undertaken to evaluate the effects of the Hydro Brake/storage installations on flooding.

Results of the draindown tests were evaluated in terms of their comparison with discharge curves of orifices of equivalent size. Measured storm flows were similarly evaluated. In addition, one year, two year, five year and ten year return period storm flows were identified from storm frequency tables, and discharge hydrographs and storage needs were then calculated from those storm flows and the observed discharge curves.

It was demonstrated that the Hydro Brakes did release storm flows to combined sewers more slowly, and at a rate more nearly independent of head, than orifices of equivalent size. The use of off-line storage tanks appeared to reduce the incidence of street and basement flooding.

This report was submitted in fulfillment of Grant No. G005370 by the City of Cleveland, Ohio, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from September, 1980 to August, 1981, and work was completed as of January 31, 1982.

DISCLAIMER

Although the information described in this article has been funded wholly or in part by the United States Environmental Protection Agency through assistance agreement No. G005370 to the City of Cleveland, Ohio, it has not been subjected to the Agency's peer and administrative review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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October 1983

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HYDRO BRAKE REGULATED STORAGE SYSTEM FOR STORMWATER MANAGEMENT

by

Timothy M. Matthews, Paul D. Pitts, Jr., R. Charles Larlham
Snell Environmental Group, Inc.
Stow, Ohio 44224

and

J. Christopher Kocsan
City of Cleveland, Ohio 44114

Grant No. G005370

Project Officer

Ralph G. Christensen
Great Lakes National Program Office
Chicago, Illinois 60604

Technical Advisors

Richard P. Traver
Douglas C. Ammon
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

GREAT LAKES NATIONAL PROGRAM OFFICE
U.S. ENVIRONMENTAL PROTECTION AGENCY
CHICAGO, ILLINOIS 60604

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CONTENTS

Foreword iii

Abstract iv

Figures vii

Tables viii

Abbreviations and Symbols ix

Acknowledgment x

1. Introduction 1
2. Conclusions 7
3. Recommendations 9
4. Method of Approach 11
    - General Procedures 11
    - Description of Hydro Brake Control Devices 11
    - Description of Installations 12
    - Simulation of Design Conditions 15
    - Storm Flow Monitoring 18
    - Precipitation Records 19
    - Water Quality Sampling 19
    - Survey of Service Area Population 20
    - Data Analysis 20
5. Results 22
    - Discharge Curves 22
    - Storm Hydrographs 29
    - Storm Water Quality 33
    - Homeowner Surveys 37
6. Design and Performance Evaluation 42
    - Design Concept 42
    - Design Criteria 42
    - Storm Simulation and Design 43
    - Evaluation of Original Design 44

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TYPING GUIDE SHEET

Hydro Brake Redesign 46
Evaluation of Hydro Brake Redesign 47
7. Comparative Evaluation of Flow Regulator 52
Installations 52
Rochester, New York 52
Nepean Township, Ottawa, Canada 56
Borough of York, Ontario, Canada 62
Comparison of Installations 62
8. Alternative Evaluation 67
General Screening of Alternatives 67
Description of Viable Alternatives 68
Cost Estimates of Viable Alternatives 68
References 70
Bibliography 71
Appendices 72
A. Formulae, Head vs. Volume Tables 72
B. Homeowner Survey 78
C. Water Quality Data 80
D. Photographs and Sediment Measurements 87
E. Design Storm Hydrographs 100
F. Cleveland Design Report 112
G. Hydro Brake Demonstration Project
Santee Drainage Area - Rochester, New York 147
(O'Brien and Gere Engineers, Inc., 1981)

BEGIN FIRST LINE OF TEXT HERE
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TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

FIGURES

Number		Page
1	Study Area Location Map	3
2	Drainage Area and Control Structure Locations	4
3	Overflow Chamber M-15	5
4	W. 170th Street Installation	13
5	W. 177th Street Installation	14
6	Puritas Avenue Installation	16
7	W. 170th St. Head-Discharge Curves: Original Design . .	23
8	W. 170th St. Head-Discharge Curves: Redesign	24
9	W. 177th St. Head-Discharge Curves: Original Design . .	25
10	W. 177th St. Head-Discharge Curves: Redesign	26
11	Puritas Ave. Head-Discharge Curves: Original Design . .	27
12	Puritas Ave. Head-Discharge Curves: Redesign	28
13	Hydrographs at W. 177th St. Control Structure - Storm of June 8-9, 1981	32
14	Hydrographs at W. 177th St. Control Structure - Storm of July 13, 1981	34
15	Hydrographs at W. 170th St. Control Structure - Storm of July 13, 1981	35
16	Hydrographs at W. 170th St. Control Structure - Storm of August 7, 1981	36
17	Basement Flooding Survey Responses	40
18	Street Flooding Survey Responses	41
19	Head-Discharge Curves - Santee Drainage Area	53
20	Head-Discharge Curve - Santee Hydro Brake	54
21	Storm of May 11, 1981 - Santee Drainage Area	55
22	Inflow-Outflow Hydrographs - Nepean Twp. Area 1 - October 30 - 31, 1976	57

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PAGE NUMBER

23 Inflow-Outflow Hydrographs - Nepean Twp. Area 2 - May 23, 1977 58
24 Inflow-Outflow Hydrographs - Nepean Twp. Area 2 - June 25, 1977 59
25 Inflow-Outflow Hydrographs - Nepean Twp. Area 2 - June 29, 1977 60
26 Inflow-Outflow Hydrographs - Nepean Twp. Area 2 - July 1, 1977 61
27 Comparison of Hydro Brake Discharge Curves 64

TABLES

Number Page
1 Hydro Brake Drainage Areas 31
2 Summary of Sampling Results 38
3 Combined Sewer Overflow Reduction at M-15 43
4 Original Hydro Brake Design - 5 year Design Storage and Discharge Requirements 45
5 Comparison of Hydro Brake Discharge Rates - Original Design vs. Redesign 47
6 Design Hydrograph Parameters - 1/2 hour storm Rainfall and Intensity 49
7 Comparison of Hydro Brake Discharge Rates and Storage Volumes for Original Design vs. Redesign 49
8 Summary of Hydro Brake Control/Retention for 1/2 hour Duration Design Storms 51
9 Analysis of Peak Flow Attenuation for 2 in. Unit 56
10 Comparison of Rated and Actual Hydro Brake Discharges . . . 65
11 Cost Comparisons of Storm Flow Control Alternatives 69

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

CFS/cfs --- cubic feet per second
cm --- centimeter
cm/hr --- centimeters per hour rainfall intensity
CMP --- corrugated metal pipe
CSO --- combined sewer overflow
ft^2 --- square feet
ft^3 --- cubic feet
ha --- hectare
in --- inch
in/hr --- inches per hour rainfall intensity
km --- kilometers
L --- liter
L/s --- liters per second
mm --- millimeter
M --- meter
ml/l --- milliliters per liter
mg/l --- milligrams per liter
RCP --- reinforced concrete pipe

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SECTION 1

INTRODUCTION

BACKGROUND

The City of Cleveland has long been plagued with most of the well-documented problems which beset urban centers served by combined sewer systems. Such systems are subject to overflow problems as a matter of design. Combined sewer overflows (CSO) are designed into these systems as the primary method of relief when flows exceed the capacity of the receiving sewers. However, while it provides hydraulic relief for receiving sewers and sewage treatment plants, CSO often carries heavy loads of pollutants to streams and water bodies. This is especially true of the "first flush" waters from an intense storm.

CSO occurrences can be eliminated, or their impacts attenuated, by a variety of documented, generally effective and acceptable methods. However, these methods are not always effective in relation to another set of problems often associated with combined sewer systems - basement and roadway flooding. Those CSO problem solutions which include flow retardation may exacerbate flooding problems.

In addition, CSO itself often provides relief only for areas downstream from most of the sewer system. Upstream areas have no external area to which overflow may be routed. Thus, the system is relieved by surcharging into basements, or to the ground (usually the roadway) surface. Surcharging and flooding represent very evident health hazards. Structural damage as a result of hydrostatic pressure and/or wash-out, as well as damage to personal possessions, are also frequent occurrences.

For all of these reasons - water quality, health, safety and property damage - control of CSO and combined sewer surcharging has become very important in recent years.

Over the past several years, numerous investigations have been undertaken to determine cost effective methods of abating CSO without making flooding worse, or to abate flooding and surcharging without increasing CSO. Much of this effort has concentrated on upstream stormwater, and methods of retaining it without worsening local flooding.

One method has been to provide storage of upstream stormwater, with release to receiving sewers after downstream stormwater has drained. This approach avoids upstream flooding by not allowing stormwater into sewers until capacity is available, and avoids downstream surcharging and CSO by permitting downstream flow to be conveyed away before upstream flows can arrive.

Various approaches to upstream storage have been devised: roof storage, roadway storage, in-line or off-line storage with reduced discharge orifices and offline storage with discharge pumps.

The City of Cleveland and the EPA Great Lakes Demonstration Program undertook the investigation of the effectiveness of off-line storage with release controlled by a proprietary device, the Hydro Brake, which purportedly permits discharge at a relatively constant rate.

PROBLEM DEFINITION

The Puritas Avenue - Rocky River Drive area of the City, chosen for this investigation, encompasses approximately 115 (46.6 ha) acres. Of this, 9.0 acres (3.6 ha) contribute flows to the Hydro Brake Structures (Figures 1 and 2). This area is served entirely by combined sewers. The area was primarily developed during the 1920's as a medium density residential neighborhood.

The combined sewers in the neighborhood carry sanitary flows, as well as roof drain, weeping tile, driveway drain and street flows. All flows from the area are ultimately conveyed to a CSO chamber (M-15 - Figure 3) via a 42 inch (1.1M) sewer, from which a 36 inch (0.9M) sewer conveys flows which do not exceed its capacity to the Southerly Sewage Treatment Plant. Flows in excess of the capacity of this sewer are discharged into a 60 inch (1.5M) CSO sewer, which connects to a 78 inch (2.0M) sewer discharging to the Rocky River.

Downstream of M-15, 507 acres (205 ha) of land are tributary to the 78 inch (2.0 M) sewer. Land uses are industrial and residential, and during storms which produce CSO from M-15, backwater from this area affects performance of the Puritas Avenue area sewers.

Overland storm drainage within the demonstration area is discontinuous, resulting in street flooding at low road points during sewer system surcharge. Basement flooding also occurs throughout the area during severe rainfall events.

During the design phase of this project, an actual storm event with cumulative rainfall approximately equal to a five-year storm was used in a sewer system response simulation to further define the extent of the CSO and combined surcharge problems. The Simulation indicated that the Puritas Avenue 42 inch (1.1M) sewer was surcharged at an average loading ratio of 2.0, (i.e., it was subjected to a flow rate double its capacity). Tributary sewer ratios averaged 1.5, and ranged from less than 1.0 to 3.0. An analysis of this storm indicated that some basement floodings would occur every six to nine months, with CSO occurring every four to six months.(1)

OBJECTIVES

The primary objective of this investigation was to evaluate the ability of the Hydro Brake to effectively regulate specific design flows from stormwater storage structures to such an extent that receiving sewers could be protected from surcharging and creating CSO conditions.

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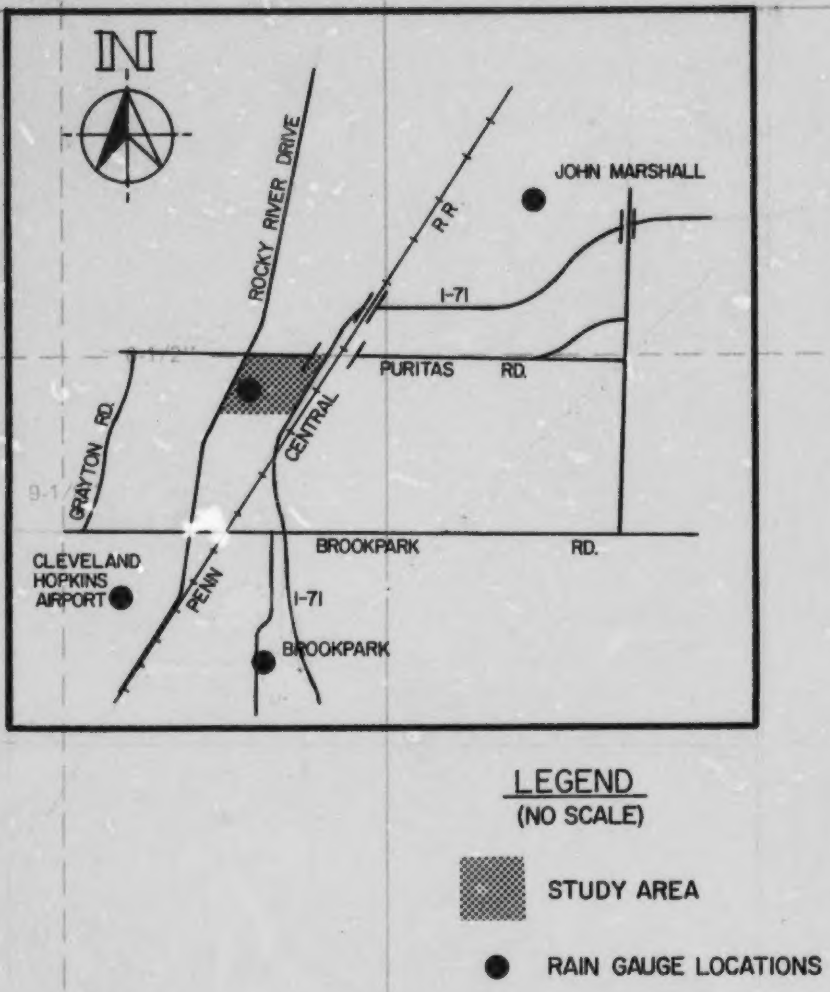
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CLEVELAND HOPKINS AIRPORT
PENN
I-71
BROOKPARK
LEGEND
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▨ STUDY AREA
● RAIN GAUGE LOCATIONS

FIGURE-1 STUDY AREA LOCATION MAP

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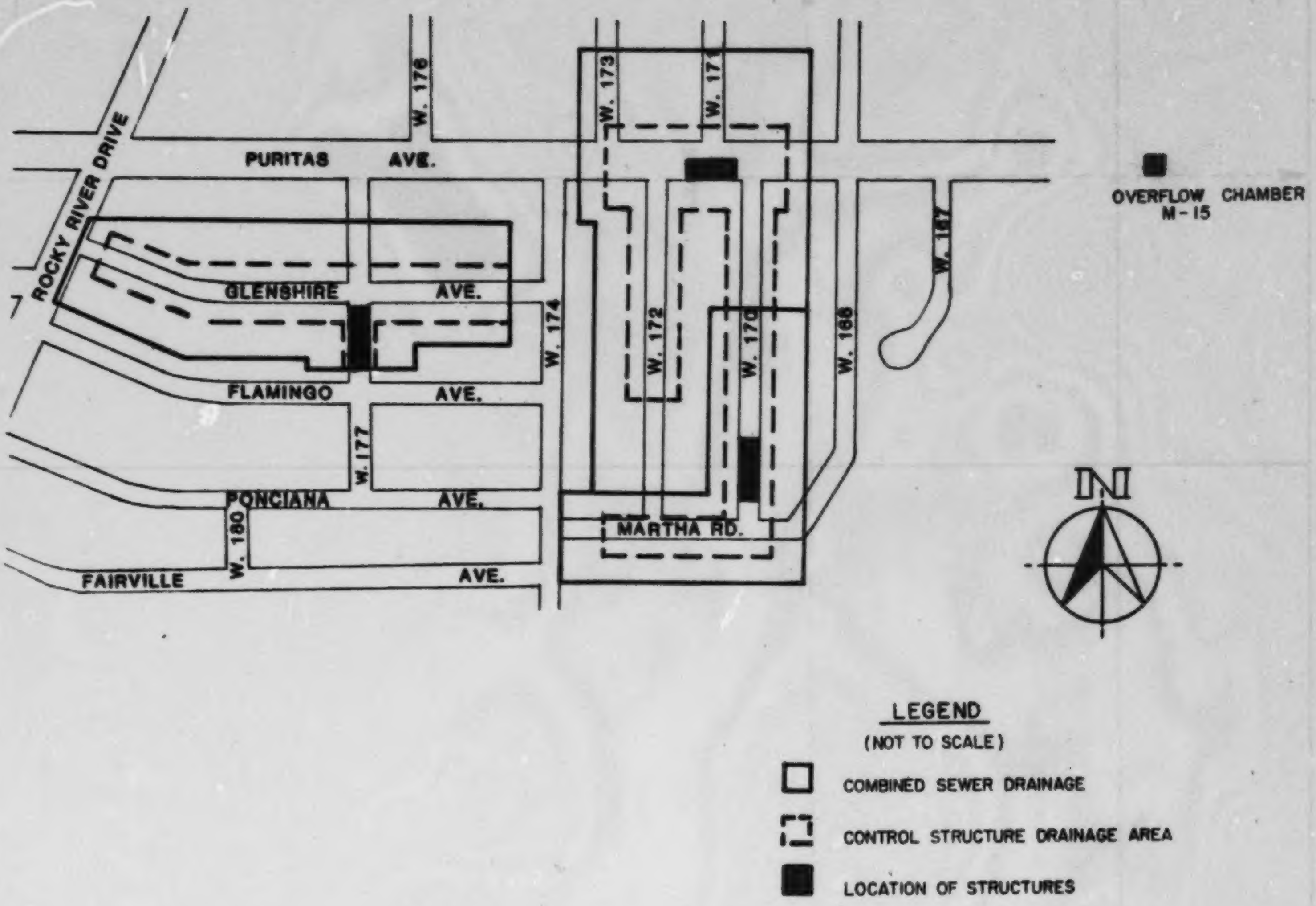
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W. 180
W. 174
W. 173
W. 172
W. 171
W. 170
W. 168
W. 167
MARTHA RD.
OVERFLOW CHAMBER M-15
N
LEGEND
(NOT TO SCALE)
COMBINED SEWER DRAINAGE
CONTROL STRUCTURE DRAINAGE AREA
LOCATION OF STRUCTURES

FIGURE 2 DRAINAGE AREA AND CONTROL STRUCTURE LOCATIONS

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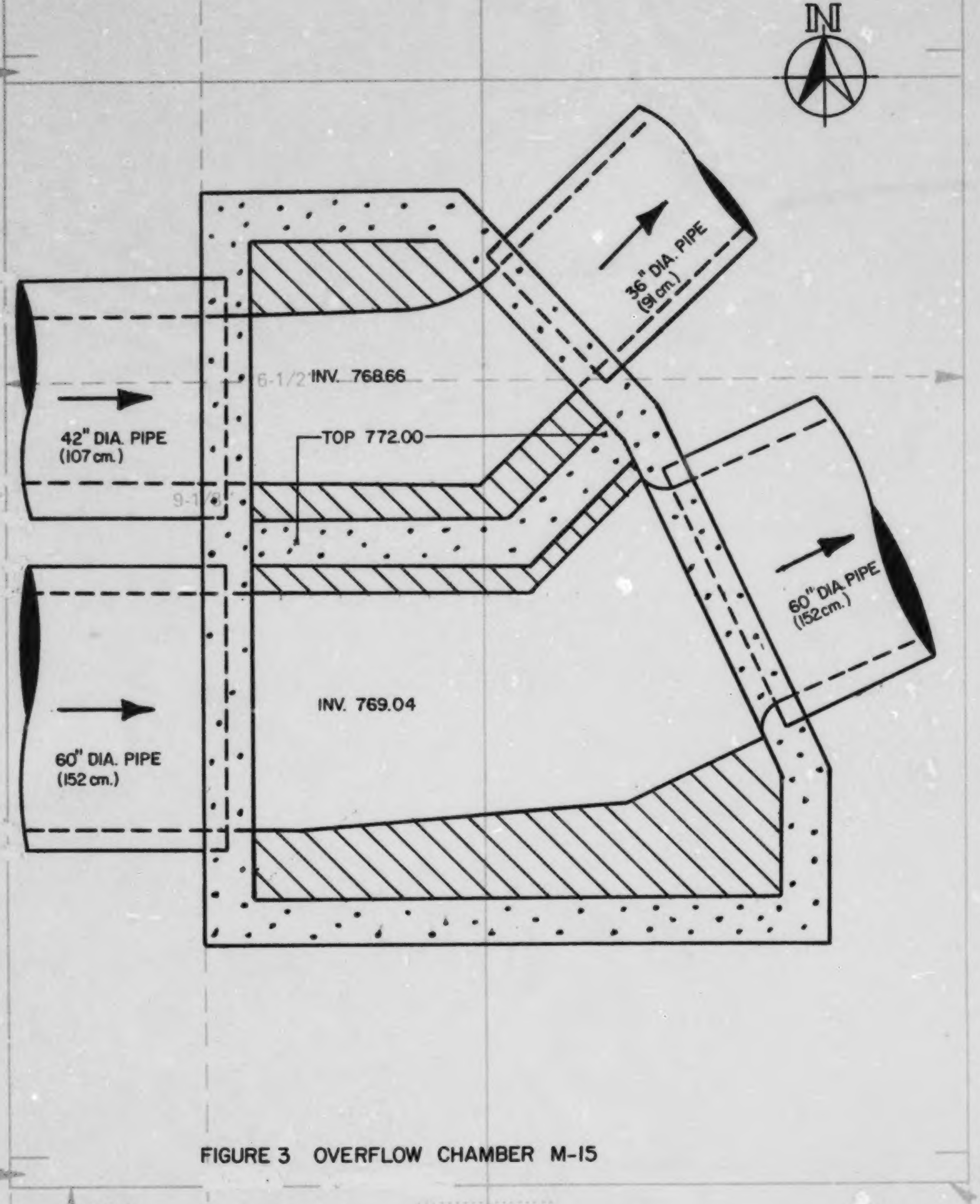
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FIGURE 3 OVERFLOW CHAMBER M-15

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The secondary objective of this investigation (although undoubtedly the primary concern of the residents of the study area) was to reduce flooding in the study area.

SCOPE OF STUDY

Three off-line underground stormwater storage units were installed in the study area, and a Hydro Brake was installed in each. The following monitoring and evaluation tasks were then performed:

1. Five storm events were monitored for inflow, hydraulic level in the unit and discharge. Discrete and composite water quality samples were taken from the storage tanks and analyzed, and observations of sedimentation were made. Discharge curves were developed and analyzed for the three devices.

2. In addition to the above monitoring and analysis, observations of the operating characteristics of the devices were made, homeowner interviews were undertaken, and other similar installations were comparatively analyzed from reports.

3. From the above information, an analysis of the efficacy and cost effectiveness of the off-line storage/Hydro Brake system as a CSO attenuation and flooding relief approach has been prepared.

SECTION 2

CONCLUSIONS

This study has examined the performance and design concept of the Hydro Brake method of inlet control for regulation of peak runoff rates and temporary storage of storm flows. This application was evaluated in relation to its ability to reduce combined sewer surcharge and resultant combined overflows.

This evaluation offers the following conclusions:

1. The Hydro Brake device does regulate flow rates at relatively constant levels once an effective operating head has been developed. Conversely, the device behaves as an orifice below the effective range of heads. Hydro Brake flow rates above the effective operating head are substantially lower than those for an orifice or other clear opening of the same size.

2. The flow regulating capability of the Hydro Brake causes reductions in combined sewer overflow peak rates and total volumes by reducing the stormwater inflow rate to the sewers upstream of the control point and by delaying the drainage of storm runoff.

3. By removing the peak rate surge from the sewer system, combined overflow pollutant loadings are reduced because the first flush effect is dampened.

4. Hydro Brake regulation of peak inflow rates is effective in alleviating sewer surcharge and basement flooding problems.

5. Percentage reduction in peak flow rates by the Hydro Brake device is dependent upon the percentage of total runoff which can be intercepted, as well as the level of control and discharge rate desired. Discharge rates may be lower than available excess capacity in receiving sewers, depending upon the availability of surface storage and/or the feasibility and expense of additional below grade storage.

6. Inlet control for purposes of storm water flow rate regulation may be accomplished with orifices, but the orifice size must be smaller than the Hydro Brake that would be required for the discharge rate desired. The use of an orifice results in a larger range of discharge rates and a higher peak discharge rate over a given range of heads when compared with a Hydro Brake of the same size as the orifice.

7. For effective application of the Hydro Brake control/storage technology, it is important that the design approach includes accurate characterization of drainage areas and sewer hydraulics to properly identify site specific release rate requirements. The level of control desired determines the required storage volume, and the characteristics of the site determine whether to employ above grade or below grade storage, or a combination thereof.

8. Where surface ponding is an acceptable form of stormwater storage, the application of Hydro Brakes alone is more cost-effective than Hydro Brakes used in conjunction with off-line, below grade storage structures. Both applications, however, are more cost-effective than other combined flow alternatives where both surcharging and overflows are the prevailing problems.

9. The design of inlet control/storage systems and the construction of below grade storage structures and related appurtenances are the major cost elements in the application of these systems. The cost of the Hydro Brakes is a small portion of the total project cost.

10. Because the Hydro Brake is a specialty item, sufficient lead time must be allowed for manufacturing and delivery delays. Installation of the device is relatively simple where the proper clearances have been provided in control structures.

11. During the first 18 months of operation, the Hydro Brake control/retention structures exhibited minimal maintenance requirements. Solids deposition in the storage tanks is almost negligible and should not increase through time.

12. Fouling of small diameter Hydro Brake control devices with stormwater debris is possible where inlets and catch basins are not trapped. This occurred in both the Rochester and Cleveland projects.

13. The minimum practical size of Hydro Brake devices appears to be approximately 2 inches (5 cm), provided that inlet structures are trapped or otherwise constructed to capture debris this size and larger. 2 inch (5 cm) units were used in catch basins in Cleveland without any reported incidents of plugging. Smaller sizes of Hydro Brakes are possible where stormwater flows are relatively clean, as has been suggested for downspout control/rooftop storage systems.

In summary, the Hydro Brake is an effective and feasible means of controlling storm water flows. Applications are practical and inexpensive because the inlet control concept makes optimum use of existing facilities. Flexibility in stormwater storage options allows the concept to be adapted to account for site differences and varying levels of control. Finally, potential cost savings through use of the Hydro Brake technology offers methods of stormwater control where other alternatives are prohibitive in cost.

SECTION 3

RECOMMENDATIONS

As a result of this study, certain design, evaluation and operational recommendations are proposed for existing and future Hydro Brake control/storage technology applications.

1. Design of Hydro Brake control/retention systems must include accurate simulation of storm inflow effects on receiving sewers to properly identify maximum allowable Hydro Brake discharge rates. Receiving sewers should be monitored to check the validity of hydraulic modeling efforts and to verify the proper selection of Hydro Brake discharge rates.

2. Design storm runoff characteristics must be properly identified in relation to selected Hydro Brake discharge rates. An inflow/outflow continuing relationship is necessary to determine the optimum size stormwater storage requirements.

3. Identification of site specific characteristics is necessary to properly identify runoff characteristics as well as the best combination of surface and subsurface stormwater storage.

4. Surcharge indicators and receiving sewer level recorders should be utilized as necessary to identify potential applications and measure the effectiveness of existing installations.

5. Surface ponding effects of potential Hydro Brake control/storage applications should be evaluated by selective installation of control devices in catch basins prior to detail design.

6. Hydro Brake control/storage designs should be evaluated for use in existing separate storm sewer systems for sediment control and receiving stream flooding relief.

7. Hydro Brake control/storage applications should be considered in storm sewer design for cost savings through pipe size reduction, and to avoid transferring upstream flooding problems to downstream areas.

8. Hydro Brake regulated catch basins should be inspected frequently and cleaned as necessary to remove deposited debris.

9. Hydro Brake regulated catch basins, as well as unregulated inlets and catch basins, tributary to retention sturctures should be designed to trap and prevent large debris and floatables from interfering with Hydro Brake control devices. Traps should also be employed to control the release of odors from combined sewers.

10. Retention tanks should be inspected after every major storm event to establish a history of debris and silt accumulation to determine ongoing maintenance and inspection requirements and verify unobstructed entry to Hydro Brake control devices.

11. Hydro Brake control/storage project construction inspection should include flooding or pressure testing of plugs inserted in abandoned catch basin leads where stormwater flows are to be rerouted to control/storage structures. Faulty plugs reduce stormwater capture and effectively counteract the regulated release function of the Hydro Brake.

12. Periodic inspection is necessary to check the structural integrity, corrosion and performance of all control/storage structures and appurtenances. Leaks in structures and abandoned catch basin leads should be identified and sealed to insure the control/storage system is operating as designed.

SECTION 4

METHOD OF APPROACH

GENERAL PROCEDURES

Various data collection and analysis tasks were undertaken to accomplish the evaluation objectives of this study. The methods described here were directed towards measuring the performance of the Hydro Brake device as well as evaluating its applicability in relation to other methods of storm water control.

Field tasks were devised to record the ability of the Hydro Brake devices and storage structures to reduce peak storm flow rates and delay storm drainage, thereby reducing receiving sewer surcharging and decreasing the frequency and magnitude of combined sewer overflows. Additional tasks included water quality monitoring to determine runoff pollutant loadings to receiving sewers, and sedimentation measurements in the storage structures for evaluation of maintenance requirements. Homeowner surveys were performed as well to further document the effectiveness of storm water control obtained.

Data analysis efforts involved desk top modeling to evaluate design conditions and measured storm events, and the derivation of discharge curves from field simulation of design storm conditions. Further analysis was performed to provide cost comparisons with alternate storm water control methods and an evaluation of other applications of the Hydro Brake device.

DESCRIPTION OF HYDRO BRAKE CONTROL DEVICES

The Hydro Brake is a proprietary flow regulator device which purportedly acts as an energy dissipator by imparting a vortex pattern to the flow passing through the device. It is a static device which is said to develop control energy from the head above the unit, and its physical geometry. The resistance to flow is described as increasing with increasing head, thereby reducing the rate of increase of the discharge from the device. This head-discharge relationship results in a much "flatter" rating curve when compared with the discharge from unrestricted openings or orifices of the same size.

The Hydro Brake units examined in this study are described as the "horizontal conical" type. Each unit is constructed as a frustum of a cone, having a sealed lower base and an open upper base, which is the discharge side of the device, the diameter of which describes the size of the unit. The cone is oriented horizontally such that its axis defines the effective direction of flow. Flow entry is accomplished through a slot along the face of the cone between the two bases. The orientation of this entry slot and the conical shape combine to produce the spiral flow pattern inherent with the flow regulating capability of the Hydro Brake. Photographs of the Hydro Brakes presently in use in the study area may be found in Appendix D. A schematic diagram of a Hydro Brake regulator is included on page 150.

During the course of this evaluation, it was determined that a reduction in the size of the Hydro Brake control devices was required, in order to reduce the discharge rates. This subject is discussed in detail in Appendix F, Cleveland's Redesign Report. This study, therefore, discusses both the original design Hydro Brakes and the redesigned units. All data collection and evaluation tasks were performed for both the original design and redesign conditions.

DESCRIPTION OF INSTALLATIONS

Each Hydro Brake installation consists of a storm water retention structure located at the low point of a drainage area with a Hydro Brake regulator device installed at the effluent end of each structure. Discharge is to the existing combined sewers. Minor storm sewer construction and plugging of catch basin leads was accomplished in the immediate vicinity of the Hydro Brake structures to direct runoff to these units. Catch basins located in more remote locations of each drainage area were modified through installation of .05 cfs (1.4 L/s and .25 CFS (7.1 L/s) Hydro Brake devices. When surface runoff rates exceed these values, storm flows bypass the catch basins, flow along the street gutter system, and drain to the retention structures.

West 170th Street Installation

The W. 170th Street Hydro Brake control structure consists of one 48 inch (1.2 M) diameter round corrugated metal pipe, (CMP), 163 feet (50M) long, sealed at both ends to form a tank. The storage volume is approximately 2,000 ft^3 (57M^3). Catch basins are connected through an 18 inch (.45M) pipe at both ends as shown in Figure 4.

The tank is buried about seven feet (2.1M) to the invert.

The Hydro Brake is located at the discharge end of the tank and is inserted in a twelve inch (.30M) pipe which discharges to the 21 inch (.53M) combined sewer. There is no manhole at the junction of the 21 inch (.53M) combined sewer and the twelve inch (.30M) effluent line.

The original Hydro Brake unit had a manufacturer's discharge rating of 2.0 cfs (57 L/s). On July 21, 1981, a new unit rated at 1.25 cfs (35.4 L/s) was installed.

West 177th Street Installation

The W. 177th Street Hydro Brake control structure consists of two 156 foot (47.5M) long, 87" x 63" (2.2 M x 1.6M) cross section corrugated metal arch pipes, buried about eight feet (2.4M) to the invert, with a total volume of 10,000 ft^3 (283M^3). The tanks have a series of catch basins connected to them as shown in Figure 5. The two tanks are also connected together by a 24 inch (.61M) CMP. The tanks drain through an 18 inch (.46M) CMP to a manhole where another 18 inch (.46M) RCP pipe is connected, tying in a series of catch basins. The Hydro Brake unit is inserted in the 12 inch (.30M) effluent line from this manhole and is drained to the 18 inch (.46M)

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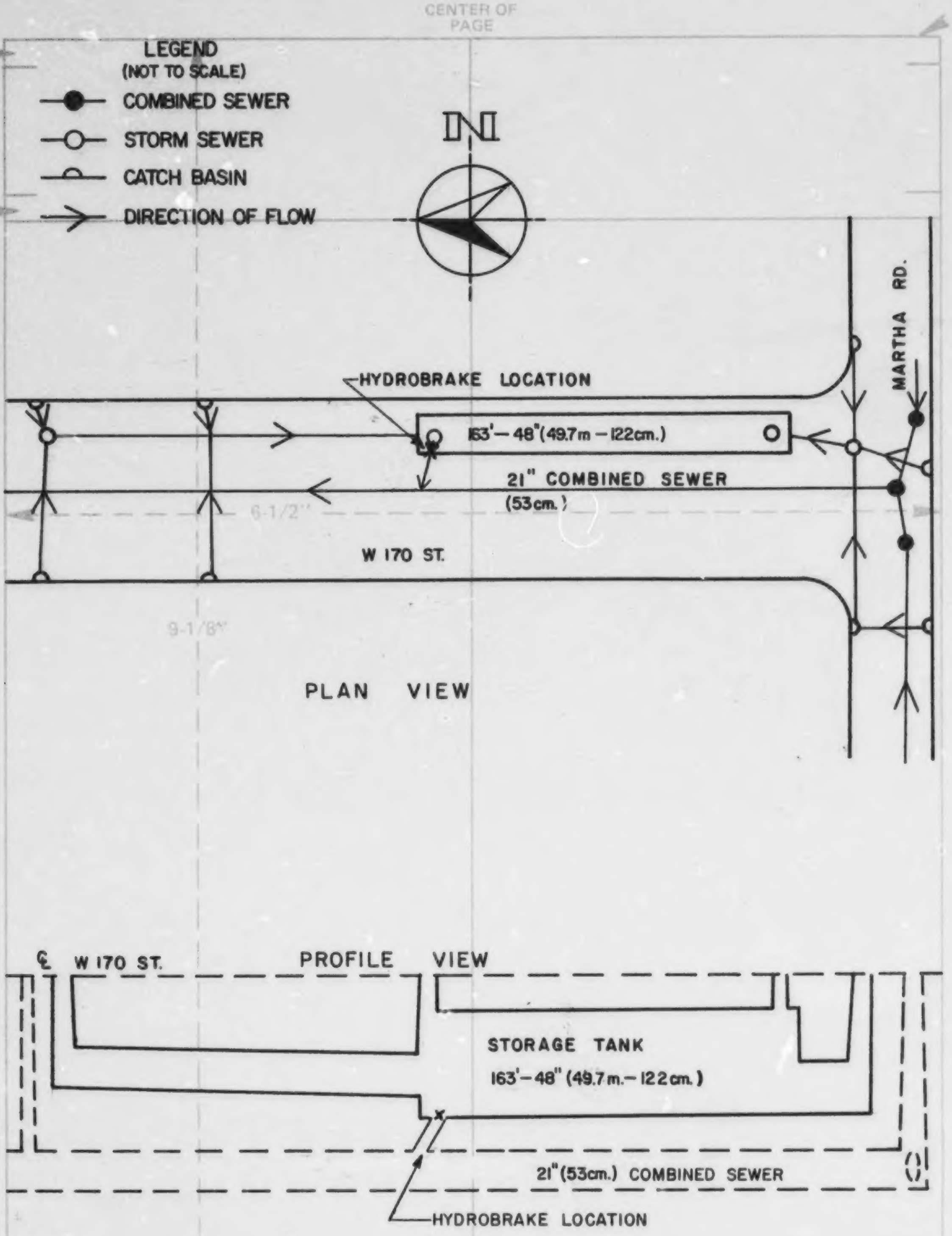
LEGEND
(NOT TO SCALE)
COMBINED SEWER
STORM SEWER
CATCH BASIN
DIRECTION OF FLOW
N
HYDROBRAKE LOCATION
163'– 48"(49.7m – 122cm.)
21" COMBINED SEWER
(53cm.)
W 170 ST.
MARTHA RD.
PLAN VIEW
℄ W 170 ST.
PROFILE VIEW
STORAGE TANK
163'– 48" (49.7m.– 122cm.)
21"(53cm.) COMBINED SEWER
HYDROBRAKE LOCATION

FIGURE 4 W. 170 ST. INSTALLATION

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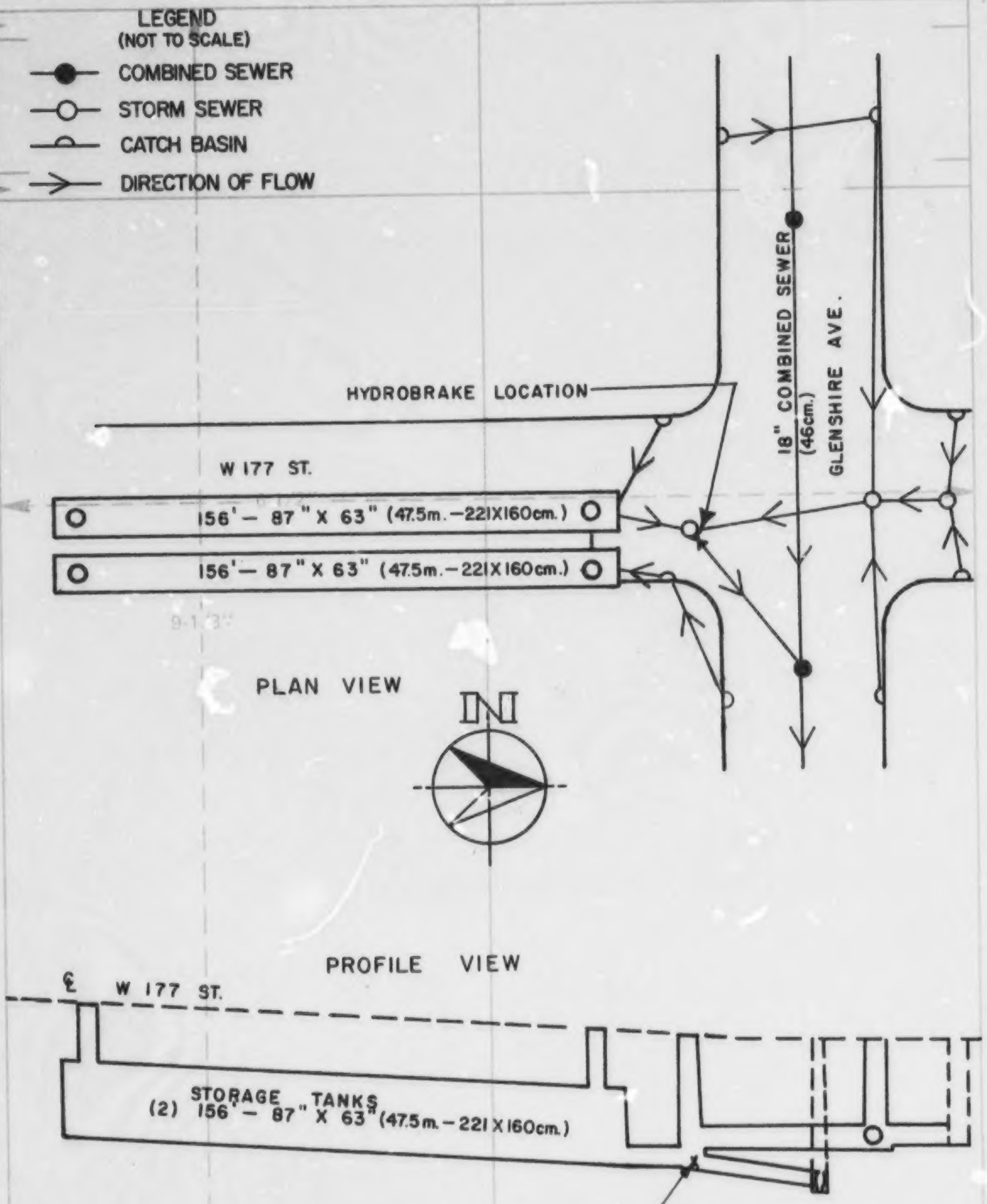
LEGEND
(NOT TO SCALE)
● COMBINED SEWER
○ STORM SEWER
CATCH BASIN
DIRECTION OF FLOW
HYDROBRAKE LOCATION
W 177 ST.
18" COMBINED SEWER (46cm.)
GLENSHIRE AVE.
156' – 87" X 63" (47.5m. – 221X160cm.)
156' – 87" X 63" (47.5m. – 221X160cm.)
PLAN VIEW
N
PROFILE VIEW
℄
W 177 ST.
STORAGE TANKS
(2) 156' – 87" X 63" (47.5m. – 221X160cm.)
HYDROBRAKE LOCATION

FIGURE 5 W. 177 ST. INSTALLATION

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combined sewer on Glenshire Avenue.

The original Hydro Brake unit that was installed had a manufacturer's rating of 1.5 cfs (42 L/s). A replacement unit was installed with a rating of 0.25 cfs (7.1 L/s), on July 21, 1981.

Puritas Avenue Installation

The Puritas Avenue Hydro Brake control structure is located under the eastbound curb lane on Puritas Avenue between W. 170th and W. 172nd Streets. The storage tank is a corrugated arch pipe 170 feet (52M) long with a cross section of 95" x 67" (2.4M x 1.7M). It is buried about ten feet (3M) to the invert. Total volume is 5,800 ft^3 ($164M^3$). At the downstream end the tank there is an 18 inch (.46M) spiral corrugated pipe leading to a manhole containing the Hydro Brake unit. This manhole has an invert approximately 3.3 feet (1M) below the invert of the tank. An 18 inch (.46M) effluent line from the Hydro Brake manhole discharges to the 3' 6" (1.1M) brick combined sewer. There is no manhole at that point, making access to the 18 inch (.46M) effluent line very difficult. An illustration of this control structure can be seen in Figure 6.

The original installation consisted of 7.0 cfs (197 L/s) rated Hydro Brake. On August 1, 1981, a new unit rated at 1.0 cfs (28 L/s) was installed.

SIMULATION OF DESIGN CONDITIONS

Introduction

In order to simulate design storm conditions (full storage utilization and maximum head on the Hydro Brake) and to field calibrate the Hydro Brake, each storage tank was filled from street fire hydrants and a record of the drain down time was made. Data collected was used to derive discharge relationships as described below.

The total storage volume at each location was calculated, and then was reduced to incremental volumes for each one-inch (2.5 cm) reduction in water depth. Since two of the storage tanks were corrugated arch pipe, and the third was corrugated round pipe, geometric formulae were used to calculate incremental volumes (Appendix A).

All influent lines were plugged, as was the Hydro Brake, in each tank, and the tank was filled from fire hydrants. After filling, water levels in each structure were observed. If the water level was observed to drop prior to pulling the Hydro Brake plug, leaks in the system or in the plug were identified and corrected, if possible. The Hydro Brake plug was then pulled, and the time for each one-inch (2.5 cm) drop in water level was recorded, using a surveyor's level rod inserted in each storage tank at the discharge point and a digital totalizing stop watch. Automatic level recorders simultaneously recorded the fill and drain procedures. The effluent elevation was taken as the invert elevation of each Hydro Brake device. Each installation was tested in this manner, and retested when revisions were made in Hydro Brake sizes.

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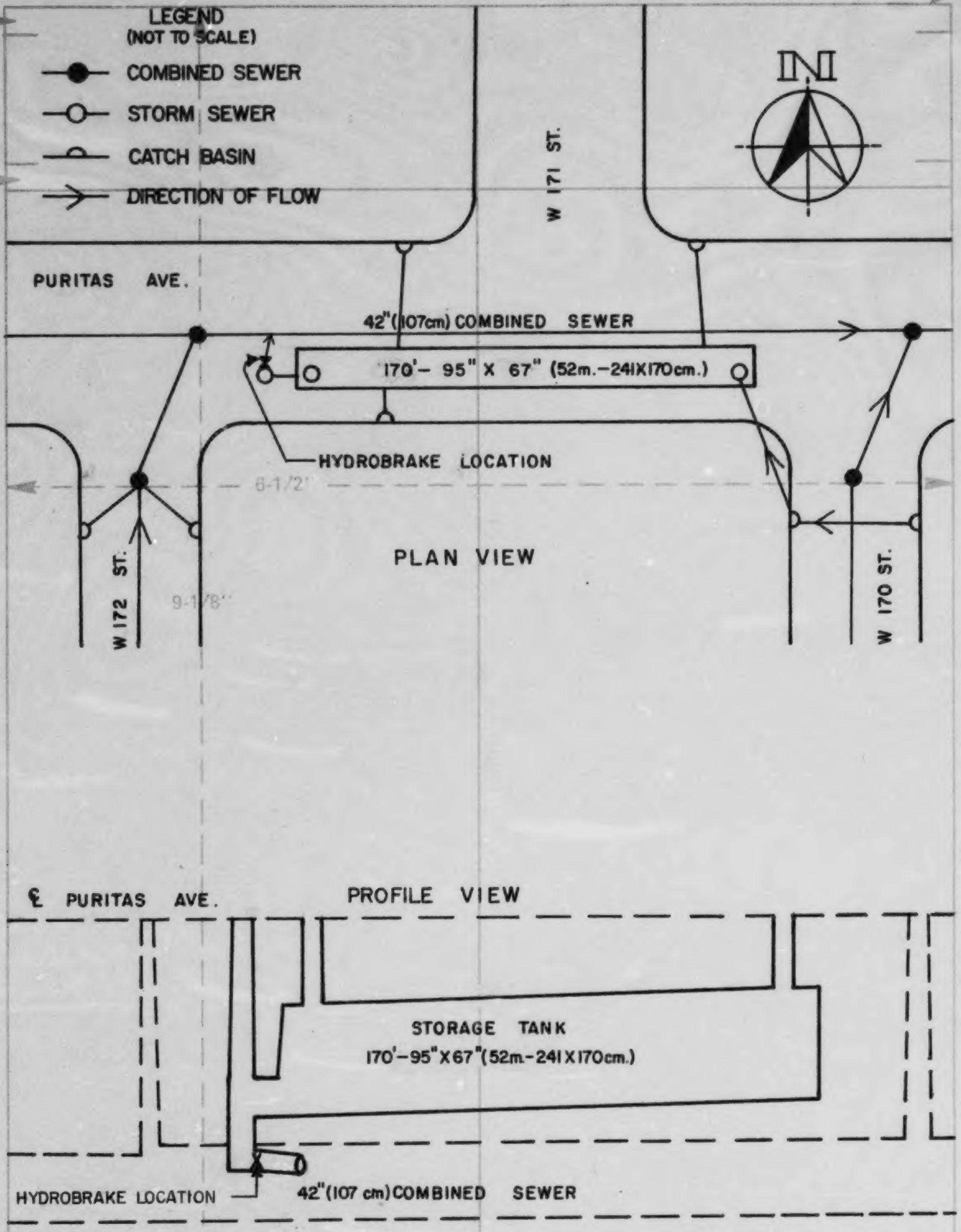
LEGEND
(NOT TO SCALE)
COMBINED SEWER
STORM SEWER
CATCH BASIN
DIRECTION OF FLOW
N
W 171 ST.
PURITAS AVE.
42"(107cm) COMBINED SEWER
170'- 95" X 67" (52m.-241X170cm.)
HYDROBRAKE LOCATION
PLAN VIEW
W 172 ST.
W 170 ST.
℄ PURITAS AVE.
PROFILE VIEW
STORAGE TANK
170'-95"X67"(52m.-241X170cm.)
HYDROBRAKE LOCATION
42"(107 cm) COMBINED SEWER

FIGURE 6 PURITAS AVENUE INSTALLATION

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Before performing discharge tests for each Hydro Brake structure, head vs. volume relationships were computed for each retention tank. Manufacturer's standard arch pipe cross sections were used for the Puritas Avenue and W. 177th Street locations. The W. 177th Street tank is a 48 inch diameter round pipe. All three tanks were constructed with a slope of 0.5%.

For calculating incremental volumes, it was assumed that the water surface in the retention structures would be horizontal during storm water storage conditions. Profile drawings of the tanks were oriented at a slope of 0.5% and horizontal planes, representing one inch (2.54 cm) increments in water depth, were constructed passing through the tanks. Cumulative volumes were then computed by increments through the full depth of the tanks, primarily by using the formula for an ungula of a cylinder. The circular cross section defines a simple cylinder, and in the case of the arch pipe tanks, the cross section defines a volume which is a composite of partial cylinders having three different radii. Sections through manholes and connecting storm pipes were accounted for as required. Formulae and head vs. volume tables may be found in Appendix A.

Calculating incremental volumes of water lost as a function of time for incremental changes in head produced a discharge rate curve for each installation. This curve was, of course, a variable head test curve, based upon a full head in the tank, and no additional water input during the test.

Each installation was tested in this manner, and retested when revisions were made in Hydro Brake sizes.

Discussions of Calibration Procedures

West 170th Street Installation:

For the calibration tests of the original unit as well as the new unit, the Hydro Brake had to be removed from the tank to gain access to the pipe. A sewer plug was allowed to fall into the combined sewer when it was released to avoid obstructing the flow in the effluent pipe during the drain down test. Calibration was then performed in accordance with procedures described previously. In both cases the 48 inch (1.2M) CMP was filled to the crown. A catch basin on Martha Avenue leaked during the first test. The leakage occurred at the plug intended to isolate it from the combined interceptor.

West 177th Street Installation:

In the manhole on Glenshire where the 12 inch (.30M) effluent line meets the 18 inch (.46M) interceptor a 12 inch (.30M) sewer plug was installed. A plug was also installed in the 18 inch (.46M) RCP in the Hydro Brake manhole to isolate the catch basins. Calibration was then performed. There were no leaks within the tanks.

After the new Hydro Brake unit was installed, a recalibration was performed. The 18 inch (.46M) RCP from the catch basins was not plugged for this test, and the additional volume associated with these structures was calculated from construction plans when the discharge curve was calculated. Subsequently, a catch basin at the northeast corner of Glenshire and W. 177th was found to have a bad plug at the point where it was isolated from the combined sewer. This severe leak allowed the tanks to be filled only to about 3' 2" (.96M). Therefore, only a partial discharge curve was measured. This causes calculated discharge values to be too high for the higher head value.

Puritas Avenue Installation:

The calibration of the original unit was done by wrapping foam rubber around an 18 inch (.46M) sewer bag and inserting it into the spiral corrugated pipe. While this plug leaked slightly around the corrugations of the pipe, the tank was still able to be filled to six feet (1.8M). Calibration was then performed as previously described.

A recalibration was performed on the new 1.0 cfs (28 L/s) Hydro Brake unit, installed on August 1, 1981. The 18 inch (.46M) effluent line at the combined sewer was plugged and the tank was filled.

As the level in the tank approached 1.7 feet (.52M) the plug blew. Following reinstallation, the maximum safe air pressure was exceeded during an attempt to better seal the discharge line. The filling proceeded to about 2.6 feet (.79M) when the plug blew out again. At this level there was approximately 6 feet (1.8M) of head on the Hydro Brake. The filling was stopped at that level and calibration was continued.

STORM FLOW MONITORING

Equipment

Bristol bubbler level recorders were installed in each tank and at CSO chamber M-15. At West 170th and West 177th Streets, strip charts set for one-half inch (1.3cm) per hour were used. Twenty-four hour circular charts were used at the Puritas tank and at the Puritas overflow. ISCO 1870 bubbler level recorders replaced the Bristol meters at West 170th and 177th Streets for approximately the last two months of the study, because of recurrent problems with the air supply systems in those two meters. All equipment was installed in concrete meter vaults which were placed on tree lawns adjacent to the storage structures and connected to the structures with underground 3 inch (7.6cm) PVC conduit. Each structure was equipped with hinged, locking steel access doors. Monitoring lines were secured in the storage structures at the invert elevation of the Hyrdo Brakes at the discharge end of each storage structure, and were connected to the monitoring equipment through the PVC conduit. In the Puritas Avenue structure, monitoring lines were installed in the invert of the storage tank at the effluent end, approximately 3.5 feet (1.1M) above the invert elevation of the Hydro Brake control device.

Data Collection

Charts were pulled weekly or after storm events, and field observations and equipment adjustments were noted. The zero level point for each level recorder was adjusted so that the level record represented depth of storm water above the invert elevation of the Hydro Brake devices. In the Puritas Avenue structure, the zero level point was set at the effluent end invert elevation of the storage tank. At CSO M-15, the difference in elevation of the bubbler tube and the overflow weir wall was measured so that a chart correction could be applied to the level recordings to accurately define any potential overflow hydrographs. Charts and field notes for each meter were maintained in a common file.

Analysis

Using the derived discharge curves for each location, outflow hydrographs were prepared for significant storm events. These hydrographs were compared with inflow hydrographs derived from recorded rainfall data to evaluate peak storm flow rate attenuation and storage utilization.

PRECIPITATION RECORDS

Equipment

A Belfort recording rain gauge with a twelve inch (30 cm), double traverse, eight-day chart was installed at Fire Station No. 43 on Rocky River Drive, approximately .25 mi (.4 km) from the center of the study area.

Data Collection

Charts were pulled weekly or after storm events, and concurrent storm information was obtained from the National Weather Service and the Northeast Ohio Regional Sewer District (NEORSD) for storm events. This supplemental rainfall information was used during the Summer, 1981 monitoring period.

Analysis

Hyetographs of rainfall data were converted into run-off (inflow) hydrographs for correlation with level and discharge data from the in-tank level recorders.

WATER QUALITY SAMPLING

Equipment

ISCO 1680 programmable sequential samplers were installed in the same manner as the flow level records in each end of the West 170th Street and the Puritas Avenue storage tanks, and at the discharge end only of the West 177th Street tank, because the influent line entered at that end also. Level actuated Mercury float switches initiated a variable time contact closure sequence to pulse the samplers.

Data Collection

Upon initiation, the samplers collected discrete samples at intervals of 2.5, 5, 10, 15, 30 and 60 minutes. At the end of the first hour, a relay eliminated intervening signals and only 30 minute samples were collected for the duration of the storm, up to a maximum of eleven hours unless the 28 bottle collector was replaced.

To accomplish the designated sample frequency, a timer was developed which would activate sampling equipment on the variable time schedule described above. The timing mechanism was activated by a mercury level switch which closed a circuit when storm flows were detected in the storage structures.

Analysis

Discrete samples were analyzed for biochemical oxygen demand (BOD_5), volatile suspended solids and total suspended solids. Samples were composited and analyzed for total organic carbon, chemical oxygen demand, chlorides, sulfates, copper, cadmium, chromium, lead and zinc.

Results were compiled and evaluated to determine whether storm water retention and peak attenuation could be shown to have an effect on receiving water quality.

SURVEY OF SERVICE AREA POPULATION

Data Collection

Two survey questionnaires (Appendix B) were developed for the homeowners of the study area. The surveys were conducted as house-to-house surveys. Residents were asked for information on flooding history prior to construction. The second survey was conducted at the end of the study, and residents were asked about flooding during the study period.

Analysis

Homeowners' pre and post-construction responses were mapped and an assessment of flooding conditions was developed. Although post-construction responses indicate a reduction in flooding of basements and streets during the study period, it is not possible to prepare a definitive analysis of project effectiveness after only one year.

DATA ANALYSIS

As noted previously, discharge hydrographs were computed using water level records from actual storm events and the stage discharge curves developed for each Hydro Brake. Calculations of inflow hydrographs, representing surface runoff from the drainage area contributing to each retention structure, were performed using the linearized subhydrograph modification of the rational method proposed by Chien.(2)

One-half hour duration storms were selected for evaluating the level of control provided by each unit because the time of concentration for each drainage area approximates this duration. Rainfall amounts were determined from the U.S. Weather Bureau Technical Paper #40, "Rainfall Frequency Atlas of the United States" for 1/2 hour storms having return periods of one, two, five and ten years. The standard time distribution of storm rainfall (Huff, 1967)(3) was used to provide rain increment input into the linearized sub-hydrograph method for computation of inflow hydrographs for each retention structure. Discharge hydrographs for these design storms were then computed using the discharge curves for each Hydro Brake and the storage continuity equation:

$$I - O = \frac{ds}{dt}$$

Where: I is inflow rate

O is outflow (discharge) rate

ds/dt is the change in storage per time increment

A more thorough discussion of the methods introduced here and the formulae involved are presented with the discussion of results presented in Section 6.

SECTION 5

RESULTS

DISCHARGE CURVES

Data collected in the variable head tests described in Section 4 were used to construct discharge curves for both original and replacement Hydro Brake control units. A plot of head v.s. flow rate was contructed from the field record of falling head v.s. time and calculations of partial volumes v.s. incremental changes in head. The head values used were averaged for each increment of volume discharge, and flow rates were computed from measured time increments for each corresponding volume increment. The datum point for each Hydro Brake was taken as the invert of each control device. Best fit curves were derived for each set of Hydro Brake test values using a commercially available curve fit program. Head discharge data pairs were input and regression analysis produced coefficients defining the equation of the best fit curvilinear relationship between head and discharge values. For each Hydro Brake, a discharge curve for an orifice having the same size opening was calculated, using the equation: $Q = .6a\ (2gh)^{1/2}$.

Where: .6 is an orifice coefficient
a is the cross sectional area of the orifice
g is the force of gravity
h is the head on the orifice

Figures 7 and 8 represent the discharge curves developed for the W. 170th Street structure, before and after redesign of the Hydro Brake control unit, respectively. The curve for the original device indicates a considerably higher discharge rate than the manufacturer's 2.0 cfs (57 L/s) rating. This can be explained in part by the faulty catch basin plug on Martha Avenue, which would increase the apparent discharge rate for the higher head values. Repairs accomplished by the City of Cleveland corrected this problem as indicated by the discharge curve for the redesigned control unit, which is rated at 1.25 cfs (35.4 L/s). Discharge rates at the higher heads indicate the new device is performing close to its rating.

The W. 177th Street discharge tests resulted in the discharge curves presented in Figures 9 and 10. The original Hydro Brake device exhibits a lower discharge rate than an orifice of the same size (7 in. - 17.8 cm) but considerably higher than the manufacturer's rating of 1.5 cfs (42 L/s). This is also the case for the redesigned unit, rated at .25 cfs (7.1 L/s), but a leaking catch basin plug on Glenshire Avenue, discovered during the second test, produces significant errors in the range of higher heads, heads, causing the discharge rates through the Hydro Brake to appear to be too high.

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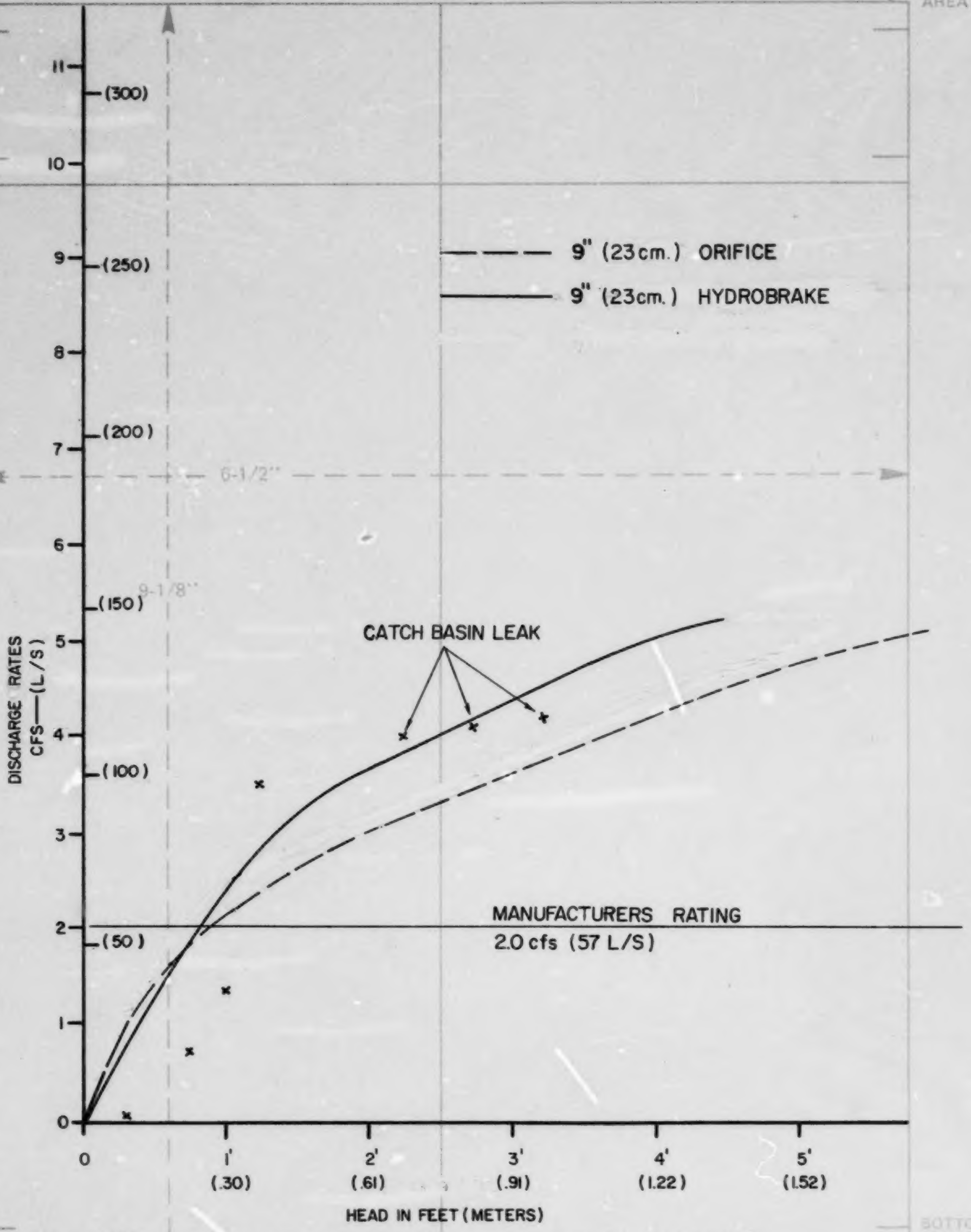

FIGURE 7 W.170 ST. HEAD-DISCHARGE CURVES : ORIGINAL DESIGN

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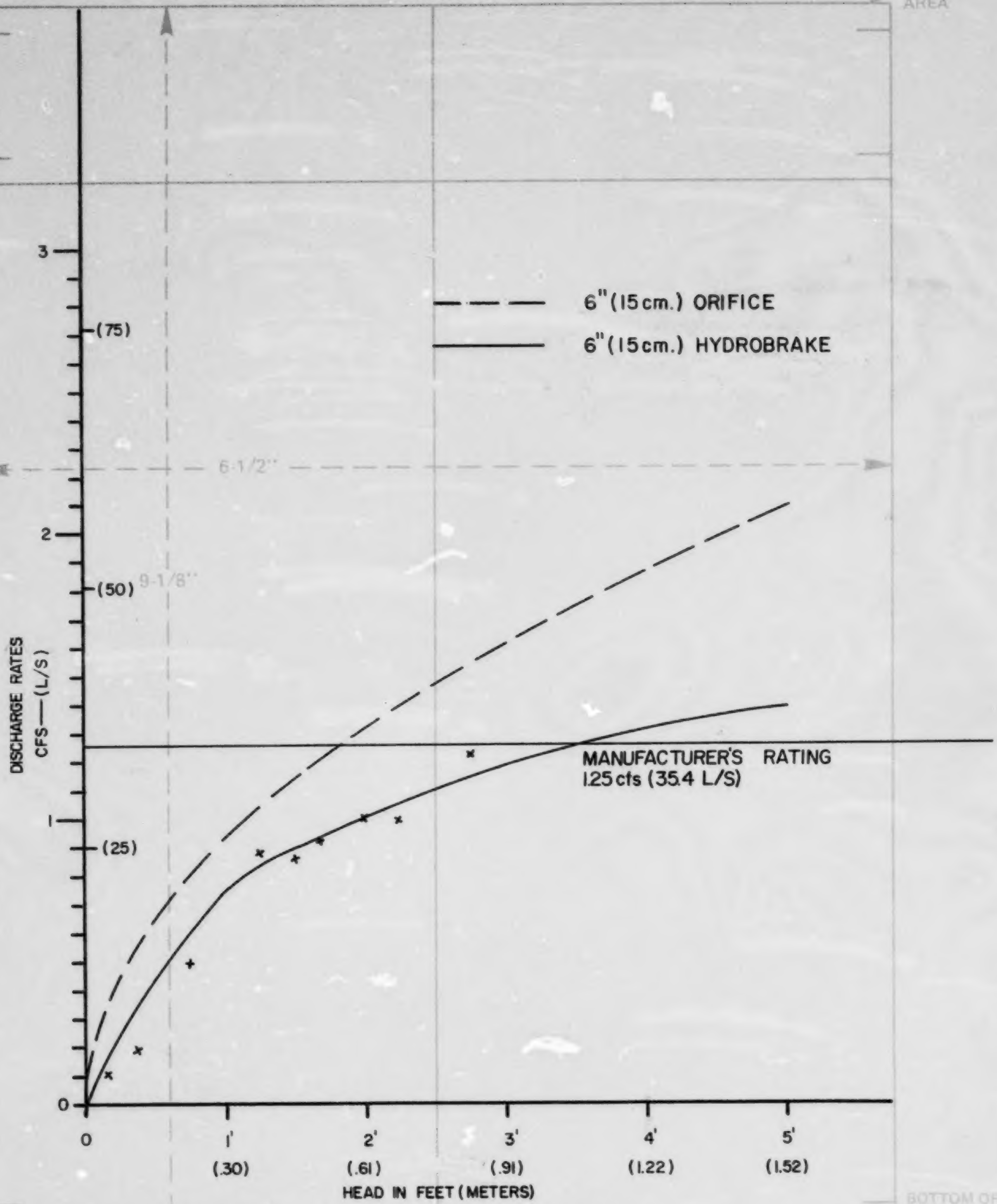

FIGURE 8 W.170 ST. HEAD—DISCHARGE CURVES: REDESIGN

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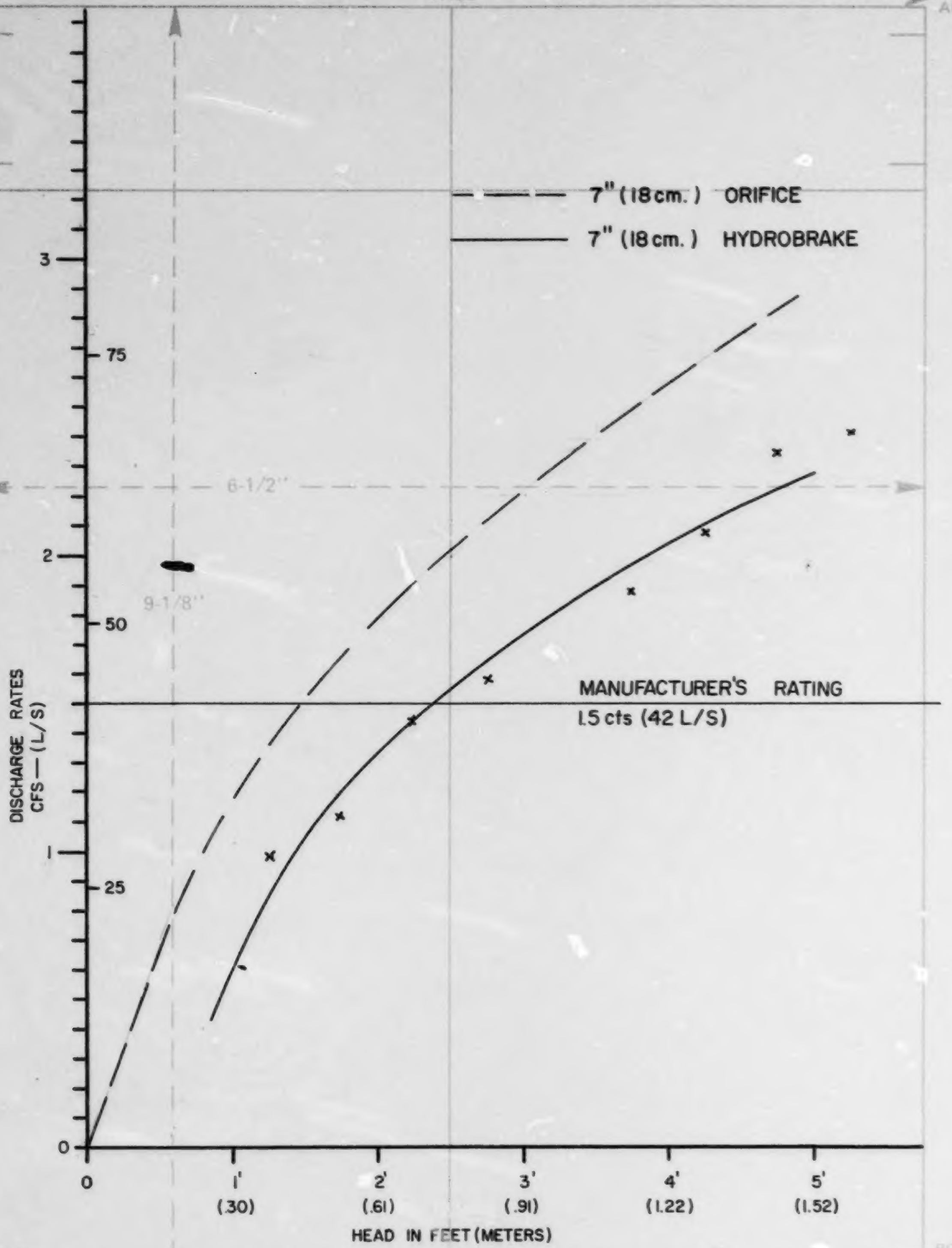

FIGURE 9 W. 177 ST. HEAD - DISCHARGE CURVES: ORIGINAL DESIGN

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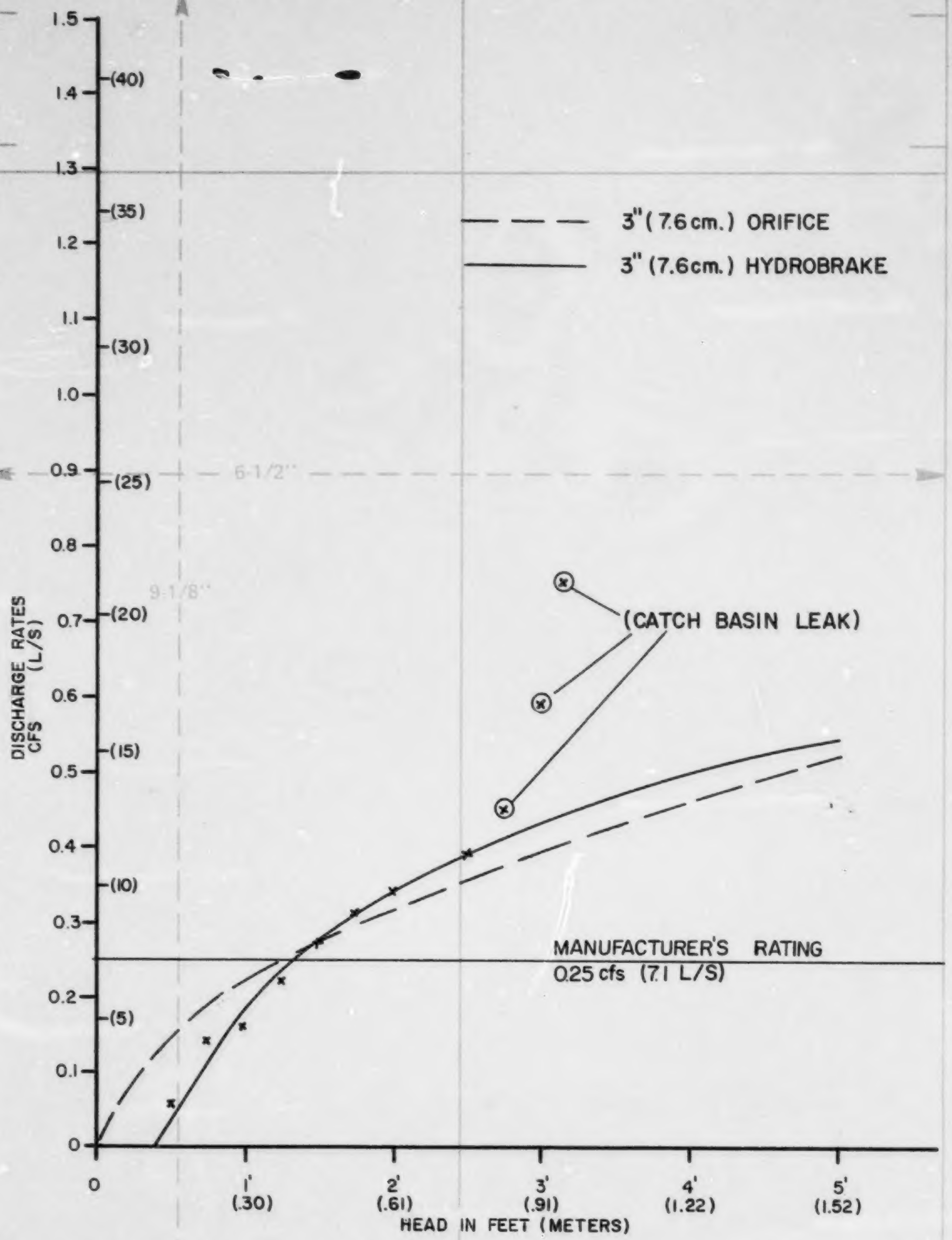

FIGURE 10 W. 177 ST. HEAD - DISCHARGE CURVES - REDESIGN

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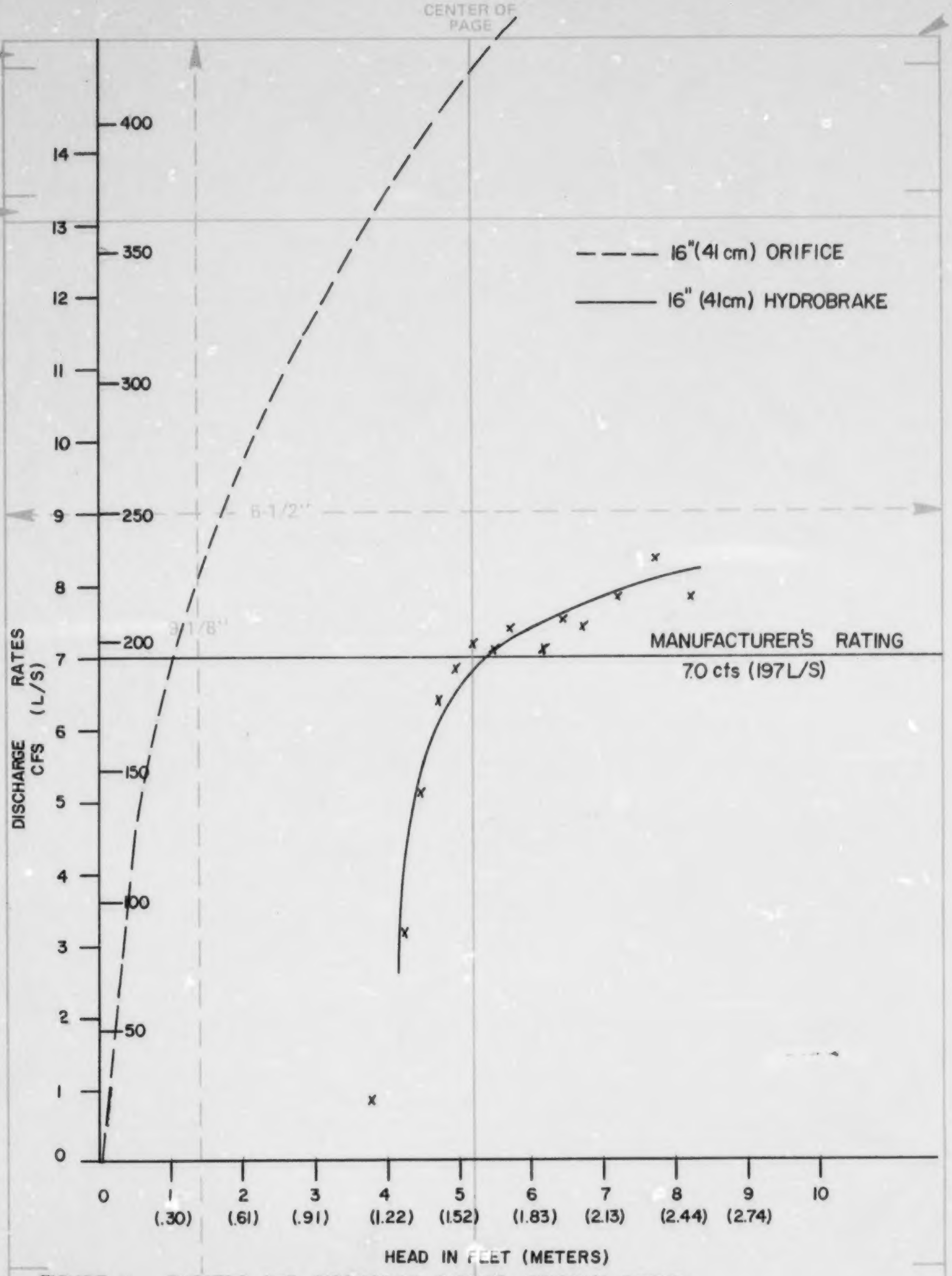

FIGURE 11 PURITAS AVE. DISCHARGE CURVES: ORIGINAL DESIGN

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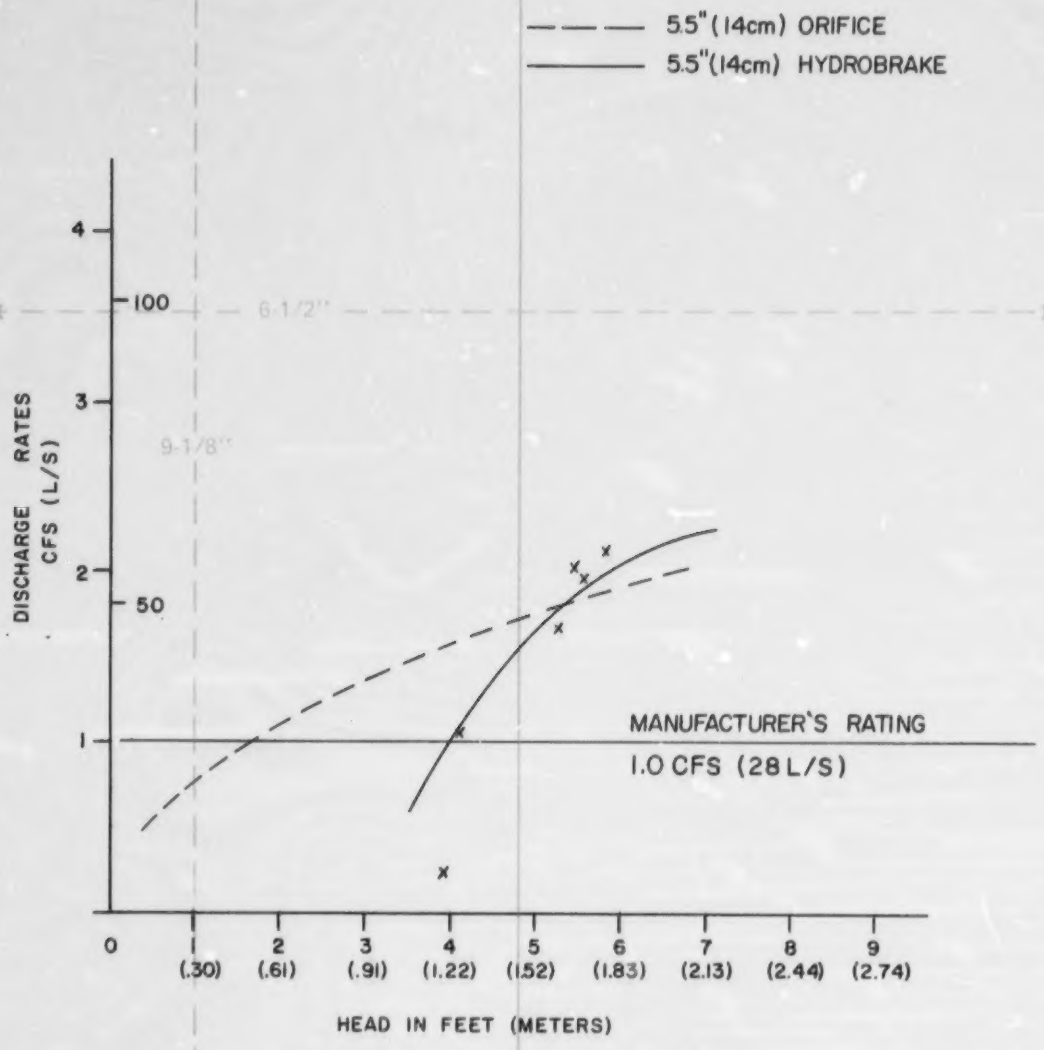

6-1/2''
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FIGURE 12 PURITAS AVE. DISCHARGE CURVES — REDESIGN

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Figures 11 and 12 illustrate the discharge curves for the Puritas Avenue structure. The downstream end of the retention tank is approxi- 3.5 feet (1.1 M) above the invert of the Hydro Brake control unit (see Figure 6), so the effective operating range of heads on the control unit is 3.5 - 9.0 feet (1.1 - 2.7 M). Essentially no control occurs between 0 - 3.5 feet (0 - 1.1 M) of head because the volume involved is negligible (44 ft^3 - 1245 L).

The discharge curve in Figure 11 indicates that the original control device performed close to its rating of 7.0 cfs (198 L/s) for actual heads of 4 to 8 feet (1.2 - 2.4 M). Data points from the second discharge test (Figure 12) indicate that the discharge rate began to stabilize around 2.0 cfs (56.6 L/s), when the head on the control unit was 5-6 feet (1.5 - 1.8 M) or 1.5 - 2.5 feet (0.4 - 0.8 M) depth in the storage structure. No measurements above this level were taken because of the problems encountered during the field test.

STORM HYDROGRAPHS

In order to assess the performance of the Hydro Brake structures and control devices under actual operating conditions, rainfall and depth of flow measurements were performed for several storms.

Measured Storm Events

Field records of actual storm events during the Fall, 1980 and Summer, 1981 monitoring periods were disappointing in that the rain events were not of sufficient intensity to cause appreciable response in the storage/control structures. Before sampling equipment was installed for the Summer, 1981 monitoring period, three moderate rainfall events were recorded on the rain gauge at Fire Station 43 on Rocky River Drive. Total rainfall of 1.87" (4.75 cm) occurred June 8-9, 1981, 1.03" (2.62 cm) occurred June 22, 1981 and .78" (1.98cm) was recorded for June 25, 1981. Peak intensities were approximately 2.3 inch/hour (5.8 cm/hr), 0.5 inch/hour (1.3 cm/hr) and 0.4 inch/hour (1.0 cm/hr), respectively. All three storms caused slight short duration overflows at the combined sewer overflow M-15 on Puritas Avenue, but it was not possible to estimate the involvement of the Hydro Brake control structures during these storms. The drainage areas which directly contribute flows to the retention/control structures account for less than 10 (ten) percent of the total drainage area tributary to this overflow point. No overflows at M-15 occurred while sampling equipment was in place at the control structure.

Three storm events which best represent the response of the Hydro Brake structures to peak flow rates were selected for illustrative purposes. These events occurred June 8-9, July 13 and August 7, 1981. The Puritas Avenus structure is not discussed here because none of the storms caused any appreciable response in this unit. Storm intensities were not of sufficient magnitude to produce stormwater inflow rates significantly storms caused any appreciable response in this unit. Storm intensities were not of sufficient magnitude to produce stormwater inflow rates significantly greater than the Hydro Brake discharge rate. Therefore, records of stormwater levels in the storage tank indicated negligible amounts of storage.

Hydrographs were constructed for the W. 177th Street unit for the first and second storms. The 1.5 cfs (42 L/s) control device from the original design was in place for these events. The W. 170th Street unit was evaluated for the second and third storms. The 2.0 cfs (57 L/s) device was in place for the July 13 storm and the 1.25 cfs (35.4 L/s) unit was in use for the August 7 storm.

Rainfall Data

In attempting to construct hydrographs for actual storm events to illustrate inflow/outflow relationships for the Hydro Brake installations, it was found that the 8 day rain records from the Rocky River Drive location could not be used to identify short duration rainfall increments. Subsequently, rainfall records were obtained from the National Weather service for Cleveland-Hopkins Airport and from Northeast Ohio Regional Sewer District for recording stations at John Marshall High School and Brookpark City Hall (See Figure 1). Though these locations are 2-4 miles from the study area, they were expected to exhibit similar rainfall patterns and provided records which could be reduced to five minute increments for use in constructing inflow hydrographs.

Inflow Hydrographs

A modification of the rational method was used to calculate inflow hydrographs for each drainage area, similar to the linearized subhydrograph method proposed by Chien.(2) Five minute rainfall increments were applied to the drainage area tributary to each structure to construct subhydrographs, which were then superpositioned with a five minute delay between successive subhydrographs to construct the total inflow hydrograph.

The formula used to construct each subhydrograph is:

$$Q = CIA\ (2\ tr)/(tr + tc)$$

Where Q = peak flow rate in cfs at time = tr
C = runoff coefficient
I = rainfall intensity in in/hr
A = contributing drainage area in acres
tr = time duration of rainfall increments
tc = time of concentration of contributing drainage area

The base of each subhydrograph is the sum of tr and tc.

From Cleveland's redesign report (Appendix F), the runoff coefficient and time of area was estimated to be .5 and 25 minutes, respectively. Drainage areas were calculated as the sum of street surface and a 30 foot (9.1 M) setback to residential structures. Table 1 summarizes these values for each Hydro Brake structure.

TABLE 1. HYDRO BRAKE DRAINAGE AREAS

Location	Total Area Acres	(hectares)	Area to Hydro Brake Acres	(hectares)
W. 170 St.	5.7	(2.3)	2.4	(1.0)
W. 177 St.	7.5	(3.0)	3.1	(1.2)
Puritas Ave.	7.9	(3.2)	3.5	(1.4)

The difference between total area and area directly contributing to the Hydro Brake structures is the roof area and yard area which drains to the combined sewers by means of area drains, downspout connections and footer drains.

Discharge Hydrographs

Discharge hydrographs were constructed from values of head vs. time recorded during storm events and the head-discharge curves which were derived for each Hydro Brake. Inflow and outflow hydrographs were then plotted for comparison purposes for the selected storms mentioned previously. Volumes were calculated by summing the areas of trapezoidal sections under each curve.

Figure 13 shows hydrographs at the W. 177th St. structure for the storm of June 8-9, 1981. The original design Hydro Brake (1.5 cfs - 42 L/s) was in place for this storm event. The rainfall pattern represents an average of the records from Cleveland Hopkins Airport and John Marshall High School, because this produces an invlow hydrograph which best matches the outflow pattern observed at the study area which is between these two rain gauge locations. Because of problems with the level recorder, the outflow hydrograph constructed from the field record indicates too small a volume for the rain observed for this event. Therefore, a discharge hydrograph was also calculated to illustrate the probable outflow pattern for this storm. This was accomplished using the calculated inflow hydrograph and the storage continuity equation:

$$I - O = ds/dt$$

Where I = inflow
O = outflow
ds = change in storage
dt = time increment

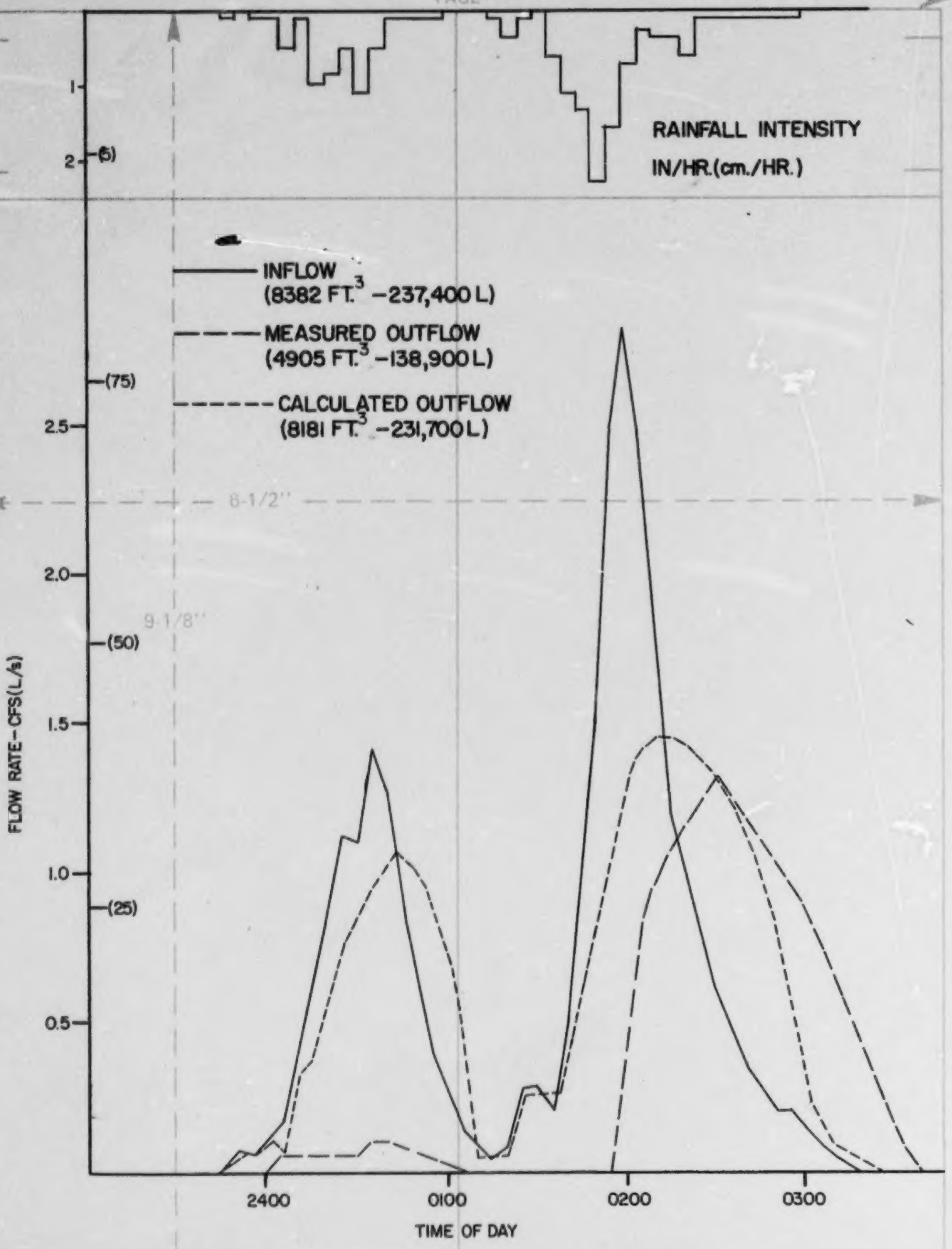

FIGURE 13 HYDROGRAPHS AT W.177 ST. CONTROL STRUCTURE
STORM OF JUNE 8-9, 1981 - 1.5 CFS (42 L/s) HYDROBRAKE

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These problems aside, this storm was selected to illustrate the ability of the Hydro Brake control device to significantly reduce high storm flow rates (the second peak in Figure 13), while lower flow rates pass through the unit with little control evident.

Figures 14 and 15 present hydrographs at the W. 177th Street and W. 170th Street locations, respectively, for the storm of July 13, 1981. The original design Hydro Brakes were still in use at this time. Rainfall records varied considerably among the four gauging locations, such that inflow and outflow hydrographs did not correlate well. It was noted that the depth of flow in all three retention structures reached a maximum of only 1 - 1.5 feet (.30 - .45 M), well below the optimum operating range of the control devices (approximately 3-5 feet (0.9 - 1.5 M)). Though some flow attenuation occurred, it appears that only sustained high intensity storms will produce any substantial peak rate reduction and storage volume utilization. This is because of the relatively small drainage areas tributary to the control points, and the high rate operating ranges of the Hydro Brake devices. Low to moderate intensity storms (less than 1 in/hr or 2.5 cm/hr) will exhibit unimpeded flow through the control structures, as was the case with most of the storms observed during the monitoring periods.

Figure 16 shows hydrographs at the W. 170th Street location for the storm of August 7, 1981, with very little control of the storm flow occurring. This is as expected when the rainfall record (Cleveland Hopkins) is examined. Intermittent high intensity rainfall is evident, but is not sufficient to generate a high rate of surface runoff.

The August 7 storm occurred after installation of the redesigned Hydro Brake control devices. The flow record from the Puritas Avenue structure shows insignificant response to this storm, and no records were available from the W. 177th Street structure. Shortly after the installation of the redesigned control unit at W. 177th Street in mid July, 1981, the device became plugged with a styrofoam cup, and the retention structure was 30% full of water for the remainder of the monitoring period. It was not possible to clear the unit before the termination of field investigations in August, 1981.

STORM WATER QUALITY

Sampling Results

It was originally intended to collect discrete samples of influent and effluent flows for storm events at the three Hydro Brake structures. as described in Section 4 Frequency of sampling was 2.5, 5, 10, 15 and 30 minutes after the onset of a storm event, to observe any first flush effects and loadings on the receiving combined sewer system. Subsequent samples after the initial sequence were taken every half hour.

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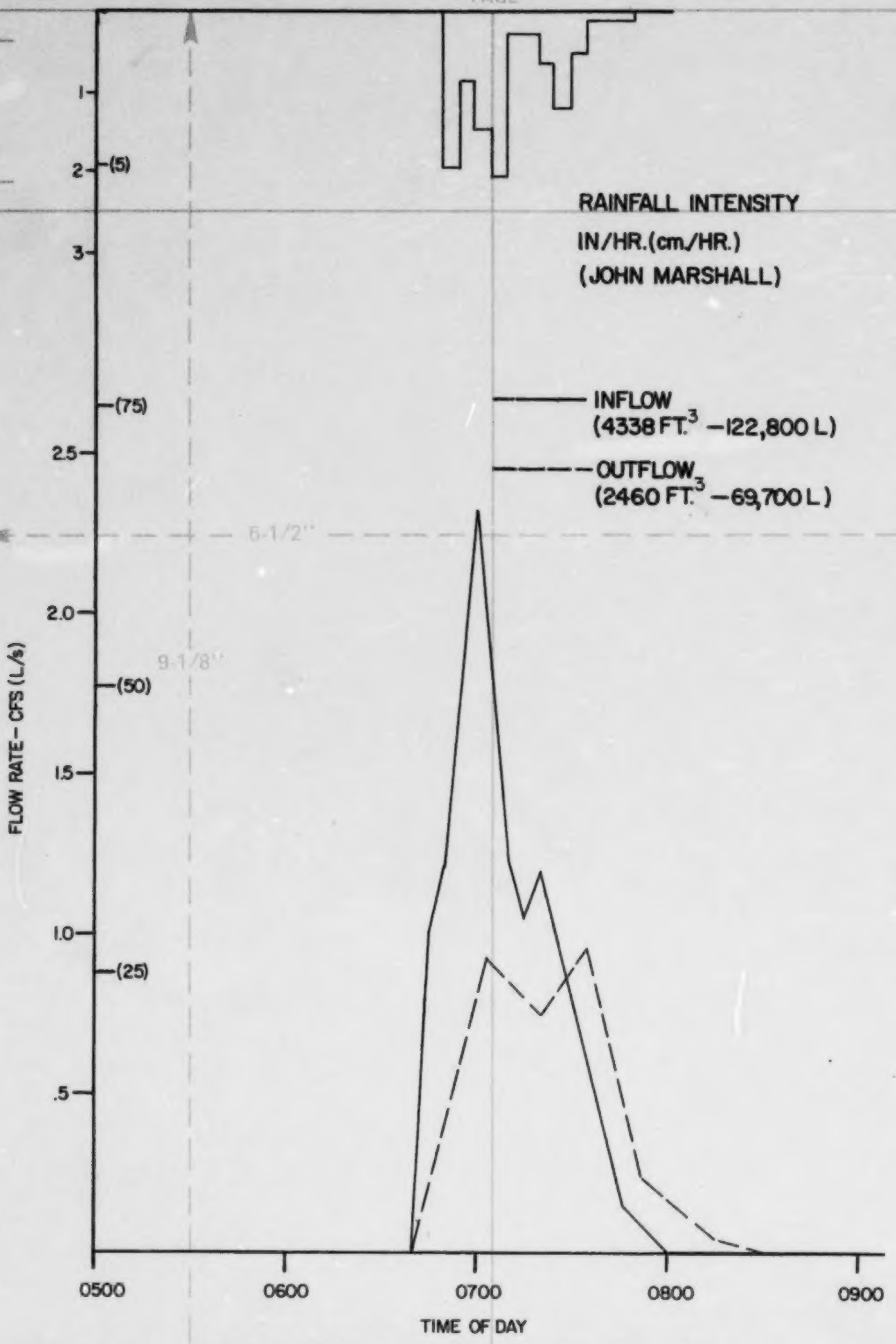

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FIGURE 14 HYDROGRAPHS AT W. 177 ST. CONTROL STRUCTURE
STORM OF 7-13-81 – 1.5 CFS (42 L/s) HYDROBRAKE

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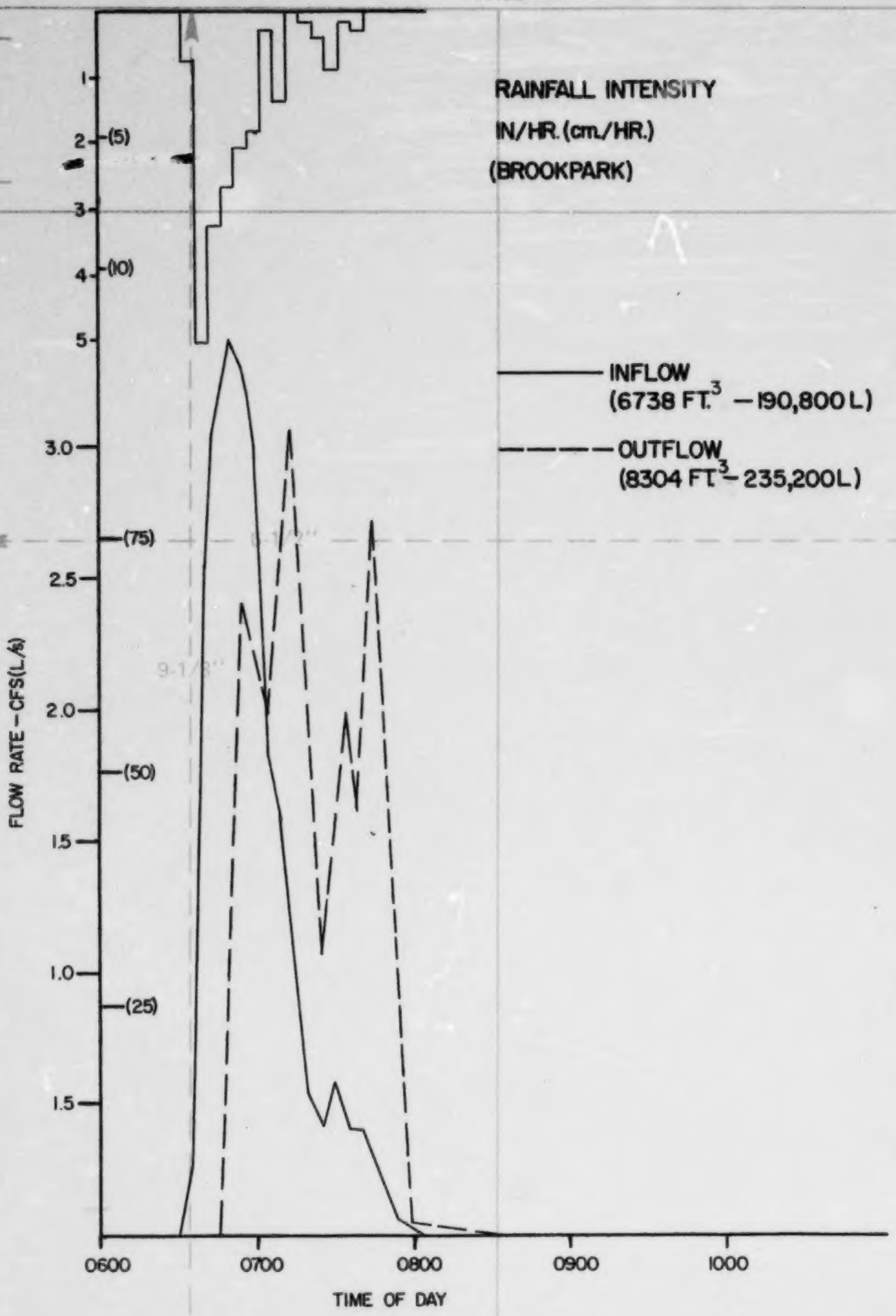

FIGURE 15 HYDROGRAPHS AT W. 170 ST. CONTROL STRUCTURE STORM OF 7-13-81 — 2 CFS (57 L/s) HYDROBRAKE

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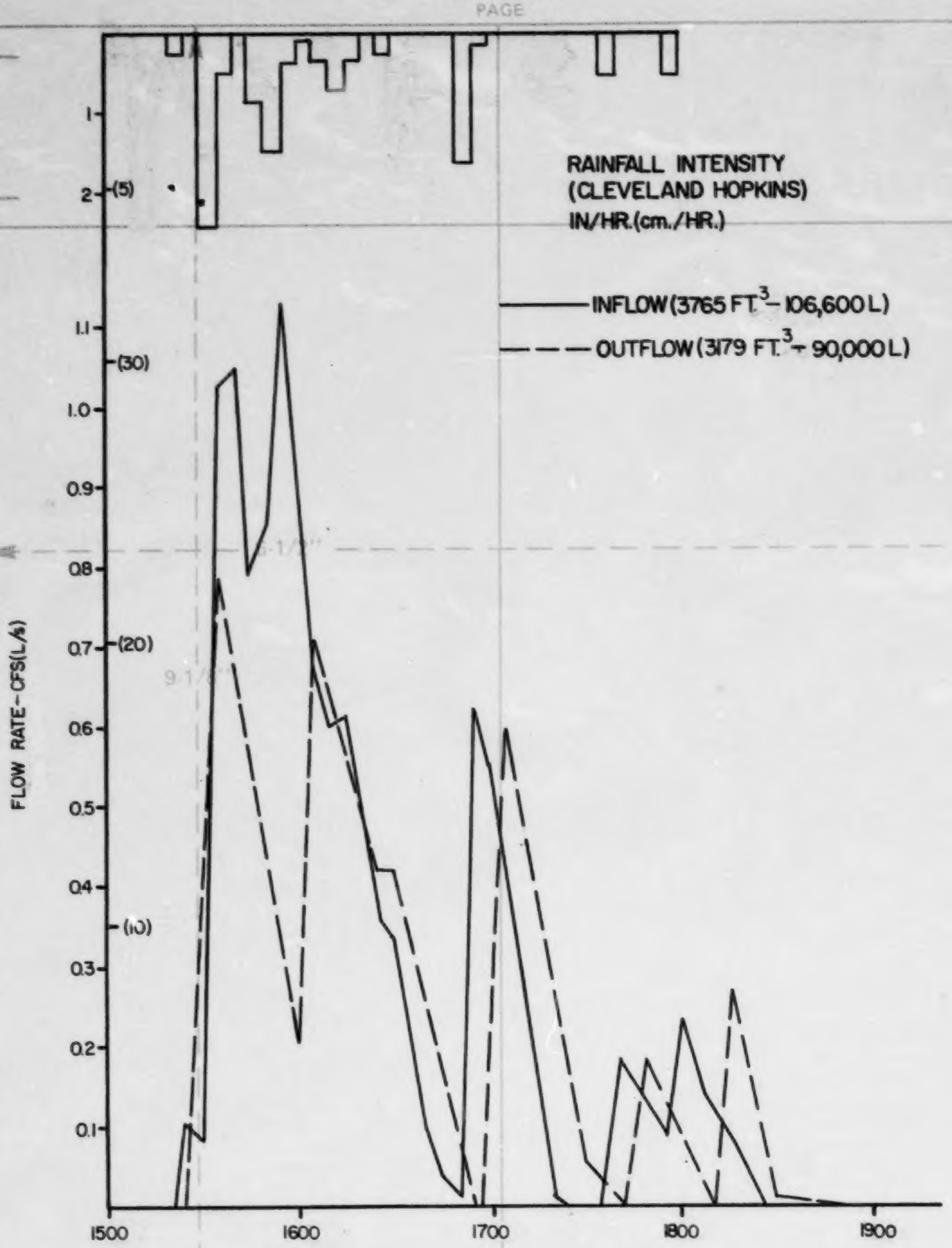

FIGURE 16 HYDROGRAPHS AT W. 170 ST. CONTROL STRUCTURE STORM OF AUGUST 7, 1981 - 2 CFS (57 L/s) HYDROBRAKE

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Sampling Results

Samples were collected for storm events as summarized in Table 2. Data presented includes the range and average of values measured at the locations indicated. Complete sampling results are presented in Appendix C. All values represent samples taken at the effluent end of each storage structure, immediately upstream of the Hydro Brake control devices.

Due to the low levels and short duration of flows in the storage structures, in addition to occasional equipment malfunctions, it was not possible to collect samples from all locations for all storm events. In all but one case, the analyses of the samples collected did not show any significant first flush effects. The loading on the combined sewers appears representative of normal stormwater flows, as the comparison in Table 2 indicates.

The sampling also provides no indications of removals or deposition within the storage structures, nor was it possible to use the sampling data to project potential solids deposition problems. This is partly because the structures have multiple influent points, and in the W. 170th Street and W. 177th Street locations, part of the influent flow enters the storage structures immediately adjacent to the effluent point.

Sediment Observations

In addition to the sampling results, field observations and measurements of the depth of solids, sediment and water along the length of each storage tank indicate that solids deposition and debris accumulation should not be a problem in the storage structures. The only exception is the redesigned Hydro Brake control unit at W. 177th Street, which could become clogged with debris, as was the case shortly after this unit was installed in July, 1981. This is apparently due to the small clear opening in this device. The Hydro Brake has an opening approximately 3 inches (7.16 cm) in diameter, and became plugged with a styrofoam cup on or about July 21, 1981. This size opening is smaller than the openings in the other Hydro Brake control devices and is, therefore, more susceptible to plugging. Subsequent installation of catch basin traps by the City of Cleveland should correct this problem.

Photographs taken in each control structure during Fall, 1981, along with a record of solids depth measurements are presented in Appendix D. These data were recorded after ths structures has been operational for approximately 18 months, and indicate minimal accumulation of solids in the retention structures over this time period.

HOMEOWNER SURVEYS

Two house-to-house surveys were conducted during the investigation. The first survey was conducted prior to completion of construction, and requested information on past flooding experience. The second survey was conducted during the first week of October, 1981, and requested information on post-construction flooding.

TABLE 2 - SUMMARY OF SAMPLING RESULTS AND COMPARISON WITH STORM WATER PARAMETERS FROM SELECTED LOCATIONS.

LOCATION	DATE	BOD_5 AVG.	mg/l RANGE	S.S. AVG.	mg/l RANGE	COD AVG.	mg/l RANGE
Cleveland W 170	7/21/81	51	51	91	91	100	-
Cleveland W 170	8/8/81	19	12-28	150	100-210	110	-
Cleveland W 170	8/17/81	20	16-23	65	48-90	53	-
Cleveland W 177	7/13/81	49	34-59	85	79-98	39	-
Cleveland W 177	7/28/81	21	10-29	71	35-110	40	-
Ann Arbor, MI	1965	28	11-62	2,080	650-11,900	-	-
Castro Valley, CA	1971-72	14	4-37	-	-	-	-
Des Moines, Iowa	1969	36	12-100	505	95-1,053	-	-
Durham, N.C.	1968	31	2-232	-	-	224	40-660
Los Angeles, CA	1967-68	9.4	-	1,013	-	-	-
Madison, WI	1970-71	-	-	81	10-1,000	-	-
New Orleans, LA	1967-69	12	-	26	-	-	-
Roanoke, VA	1969	7	-	30	-	-	-
Sacramento, CA	1968-69	106	24-283	71	3-211	58	21-176
Tulsa, Oklahoma	1968-69	11	1-39	247	84-2,052	85	12-405
Washington, D.C.	1969	19	3-90	1,697	130-11,280	335	29-1,514

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Basement Flooding

Figure 17 shows pre and post-construction survey responses with respect to basement flooding. The distribution of responses indicates that, at least for Glenshire Avenue and W. 170th and 172nd Streets, the basement flooding problem may have been improved. This conclusion is further supported when the expository comments on the questionnaire, which indicated flooding historically occurred during any heavy (or even moderate) rainfall, are considered in light of a two-inch rainfall which occurred during a two-hour period July 9, 1981. In addition, one Puritas Avenue resident indicated to field personnel that he had had no basement flooding, only since the installation of the redesigned Hydro Brake control device in July, 1981. This information was noted August 8, 1981, one day after the August 7 storm.

Street Flooding

As shown by survey responses illustrated on Figure 18, street flooding problems on Glenshire and Martha Avenues have evidently been alleviated to some degree. However, W. 172nd Street apparently still experiences some flooding. Also, storm water ponds around a catch basin and yard area on W. 168th Street, where .05 cfs (1.4 L/s) Hydro Brakes had been installed in the catch basins. The City of Cleveland has since removed the control device from the problem area.

On balance, it can be concluded that both street and basement flooding have been reduced in the study area. Basement flooding has been reduced because combined sewer surcharging has been alleviated through the use of Hydro Brake control devices, which reduce peak storm inflow rates to the combined sewers. Street flooding has been reduced through surface drainage improvements and the construction of below grade stormwater storage structures. However, it is expected that sustained high intensity storm would cause some street flooding (of a temporary nature) because the entry points to the combined sewers are restricted to eliminate surcharging of the combined collection system.

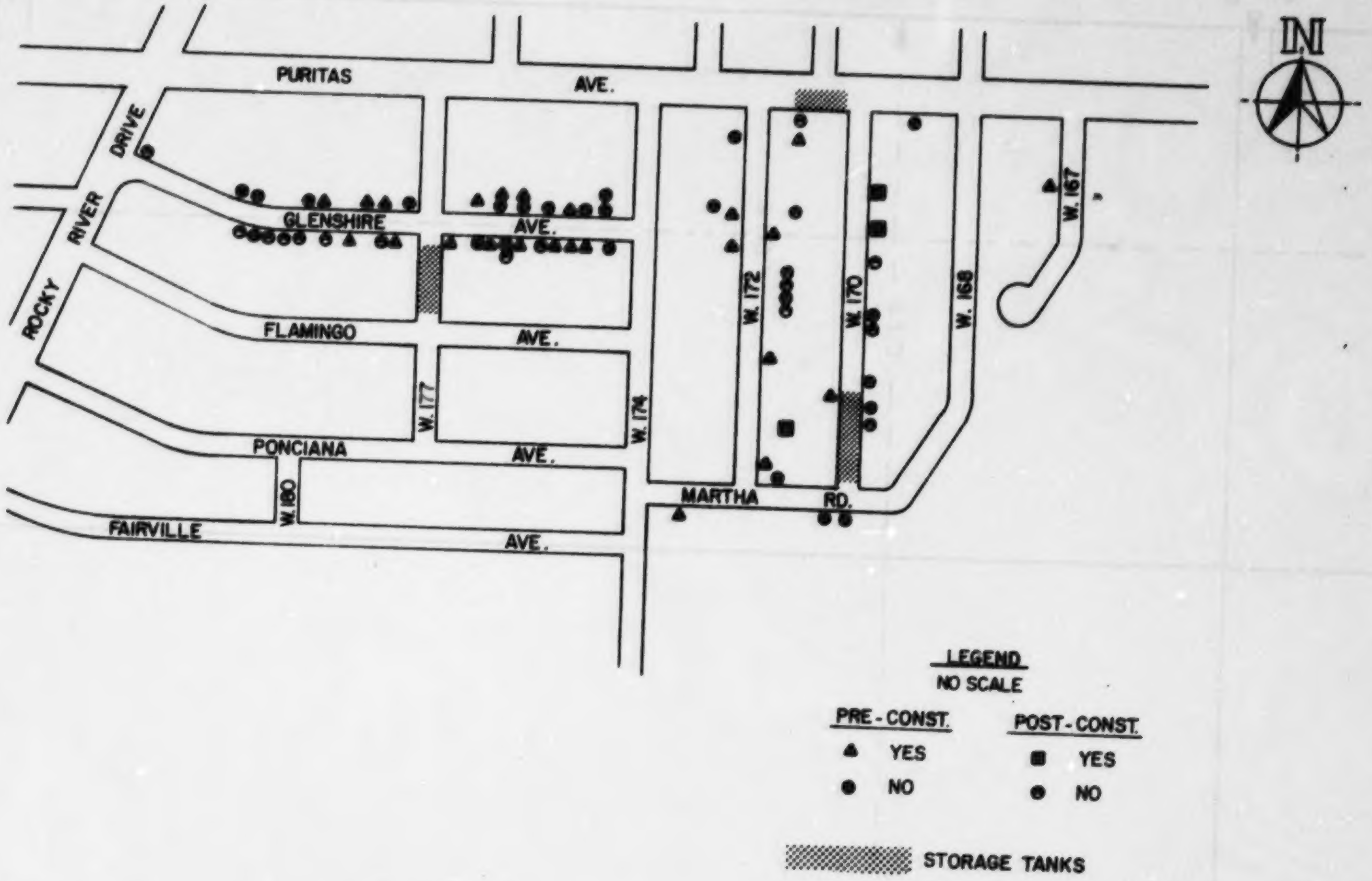
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FIGURE 17 BASEMENT FLOODING SURVEY RESPONSES

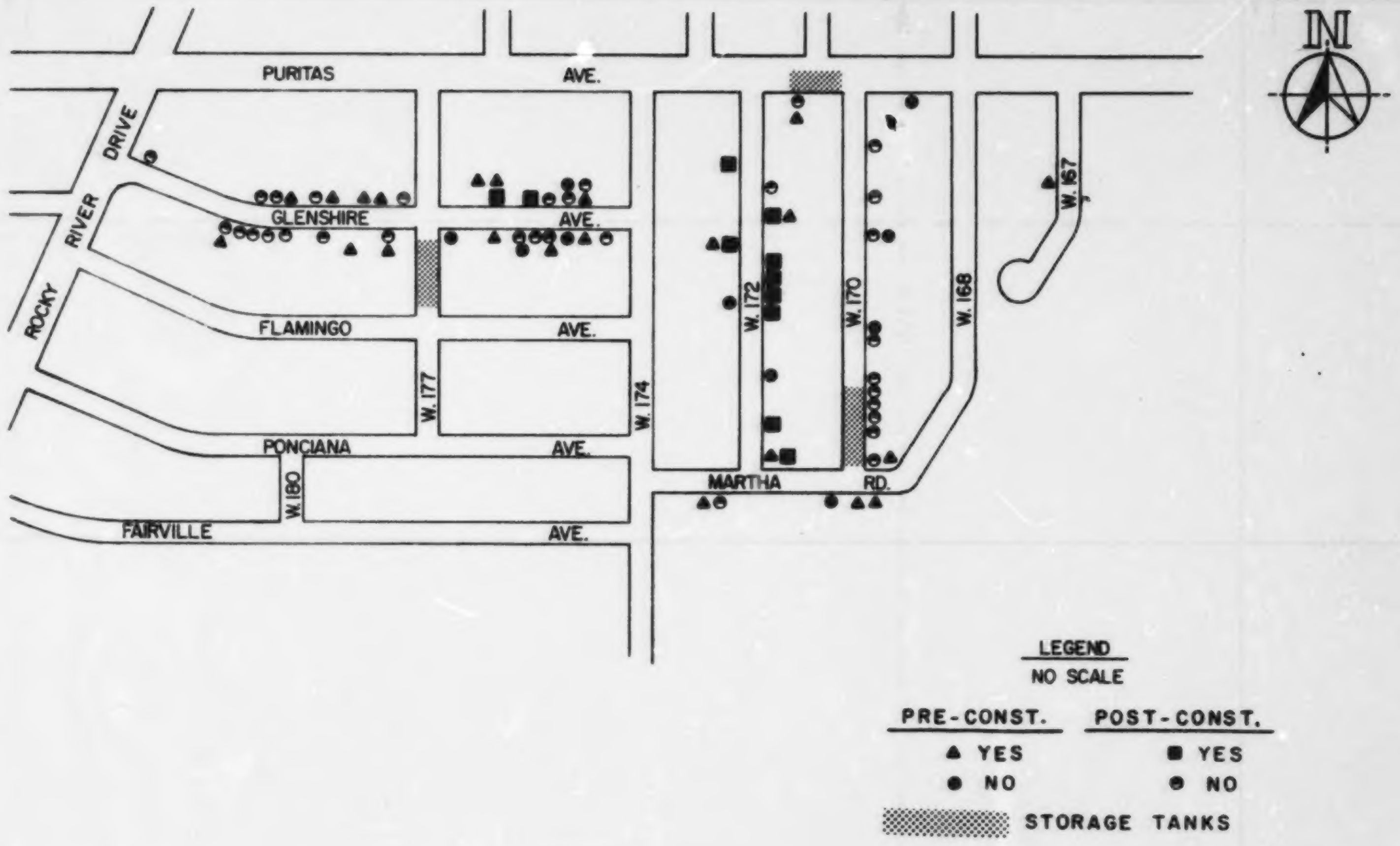
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FIGURE 18 STREET FLOODING SURVEY RESPONSES

SECTION 6

DESIGN AND PERFORMANCE EVALUATION

INTRODUCTION

This section presents a summary of the design elements employed by Thiel and Candaras (1) in the original design of the Cleveland Hydro Brake control/storage system in addition to an evaluation of the design and performance of this system. During the course of this study, it became apparent that the system was not performing as intended. Therefore, the City of Cleveland undertook a redesign effort to modify the system to better respond to actual conditions in the study area. The elements of this redesign are also presented here. All study tasks were duplicated and an evaluation parallel to that of the original design was then performed.

ORIGINAL DESIGN CONCEPT

The Hydro Brake application in Cleveland is based on the idea of regulating the inflow of surface runoff into the existing combined sewers so as not to exceed the capacity of the collector system. This is a radically different concept compared to the traditional drainage design approach of building collectors capable of handling the peak flow rates generated by some five or ten year design storm.

The Hydro Brake device is the means by which flow rates are regulated, with any excess flows stored in below grade structures or by surface ponding. In a residential area such as the Puritas study area, the practical limit to surface storage is between curbs on the streets.

ORIGINAL DESIGN CRITERIA

In order to design the flow regulation and retention structures constructed in the study area, the surface runoff parameters and combined sewer flow patterns were modelled using the proprietary Dorsch Hydrologic Volume Method.(1) This model was selected because it purportedly accounts for sewer surcharging and backwater effects from downstream areas that would result from critical storm events over the drainage area. This allowed simultaneous simulation of surface runoff and sewer system response.

Surface Runoff Parameters

Drainage areas were divided into sub-basins, all of which were assigned runoff parameters for land use, imperviousness, surface slope and roughness, depression storage, infiltration rate and flow path. Separate hydrographs were generated for different types of surfaces as well as total surface runoff hydrographs. This was necessary where certain portions of the drainage area, such as roof areas, would be routed directly to the combined sewers.

Design Rainfall

The rainfall of July 19, 1972 was selected for design purposes because the greatest number of flooding complaints occurred during this storm event and it approximated a five year return period rainfall. This corresponds with the City of Cleveland's storm sewer design standard for a five year return frequency rainfall. This storm event consisted of three high intensity, short duration peaks, with each occurring approximately one hour apart. Peak intensities (based on five minute rainfall increments) ranged from 3.1 to 3.8 in/hr (7.9 - 9.8 cm/hr), with a total accumulation of 1.96 in. (4.98 cm).

STORM SIMULATION AND DESIGN

Modeling Methodology

Using records of the July 19, 1972 storm described above, the Dorsch HVM model was employed to simulate the response of the existing sewer system, after which the simulation was repeated considering only roof area and private area drain inflow sources to the sewer system. Surface hydrographs were developed for the remaining area to identify storm flows which would be regulated into the collection system. Finally, inflow regulation rates were determined through a series of successive iterations such that flow levels were maintained below basement elevations. These flow regulation rates are the discharge rates of the Hydro Brake devices to be installed, and are based on the available excess capacity at those points in the sewer system where inflow regulation is required. An analysis of the surface hydrographs in relation to these flow regulation rates produced the required storage volume at each inflow regulation point.

Control Device and Storage Sizing

As a result of the design storm simulation, recommendations were made for storage tank sizes and Hydro Brake discharge rates, as summarized in Table 3. The design allowed for some surface ponding between curbs on street surfaces.

TABLE 3. ORIGINAL HYDRO BRAKE DESIGN
5 YEAR DESIGN STORAGE & DISCHARGE REQUIREMENTS

	Peak Inflow		Hydro Brake Discharge		Retention Tank Volume		Surface Storage	
Location	cfs	(L/s)	cfs	(L/s)	ft^3	(1000 L)	ft^3	(1000 L)
W. 170 St.	4.3	(122)	2.0	(57)	2074	(58.7)	1676	(47.5)
W. 177 St.	5.8	(164)	1.5	(42)	8984	(254)	1246	(35.3)
Puritas Ave.	13.0	(368)	7.0	(198)	6024	(170)	246	(7.0)

The estimated surface storage is only practical on lightly traveled residential streets, where it is not likely to be a traffic hazard and is very temporary in nature. Draindown of this volume occurs in approximately fourteen minutes for the W. 170th and W. 177th Street locations, and less than a minute on Puritas Avenue.

EVALUATION OF ORIGINAL DESIGN

Combined Sewer Overflow Reduction

The original design approach for the study area resulted in recommendations for a two phase plan to install seven Hydro Brake control/retention structures, catch basin Hydro Brakes in the areas tributary to the control structures and storm sewers. Modifications to overflow chamber M-15 were also recommended to improve flow patterns. Only Phase I was implemented, involving the control structures at W. 170th Street, W. 177th Street and Puritas Avenue, in addition to catch basin Hydro Brakes on W. 168th Street and the overflow chamber modifications. As part of a separate project, storm sewers and catch basin Hydro Brakes were installed in the Milburn Avenue area north of Puritas Avenue.

Because all the recommendations were not implemented, the actual reduction in overflows at M-15 is less than projected in the original design report. Overflow volume and peak rate reductions are a result of the improvements made in the subject study area and the Milburn Avenue area. Estimates of the reduction in combined overflows at M-15 which can be attributed to these improvements are presented in Table 4. These estimates take into account the removal of the Grayton Road lift station discharge which previously contributed flows to the Puritas Avenue sewer upstream of the study area. These flows were included in storm flow projections in the original design study. Peak flow rates were estimated to be 8.4 cfs (238 L/s). In the Spring of 1981, this flow was rerouted to a sewer on Rocky River Drive which is not tributary to the Puritas Avenue trunk and overflow M-15.

Because a large percentage of the overflows at M-15 is related to backwater effects from downstream areas, it is difficult to estimate overflow peak rate and volume reductions without using a surface runoff and sewer system hydraulics model. This effort is beyond the scope of this evaluation, so estimated reductions are based on the pre and post-design simulation from the original design study for those areas where flow controls were installed.

As presented in Table 4, simulation of sewer system response to the five year design storm indicates that the peak rate of overflow from chamber M-15 is approximately equivalent to the influent flow rate to this control point. This is true even with full implementation of the design study recommendations, apparently because of backwater effects from areas downstream of M-15. Therefore, estimates of overflow rates resulting from Phase I improvements reflect the same relationship.

TABLE 4. COMBINED SEWER OVERFLOW REDUCTION AT M-15 BASED ON DESIGN STORM SIMULATION - ORIGINAL DESIGN

Overflow Parameter	No Stormwater Control	Phase I & II Implementation	Phase I Implementation
Peak Inflow (cfs - L/s)	122 (3455)	47 (1311)	89 (2520)
Peak Overflow (cfs - L/s)	110 (3115)	38 (1076)	77 (2181)
Overflow Vol. (ft^3 - 1000 L)	189,400 (5364)	53,790 (1523)	121,300 (3435)

For all practical purposes, the same volume of storm water enters overflow chamber M-15 under all three levels of control, but the overflow rate and volume is reduced because of peak rate reduction at various inlet points to the system as well as flow retardation until capacity is available after the subsidence of backwater effects.

Reduction in Flooding and Surcharging

Based upon the results of the surveys of study area residents, which were presented in Section 5, it is apparent that some reduction in basement flooding has occurred as a result of the Hydro Brake controls now in place. This indicates some lesser degree of sewer surcharging than was prevalent before the control/retention structures were constructed.

To further examine the effectiveness of these controls in relation to sewer surcharging, the design simulation results for individual sewer segments were compared to pipe capacities. Simulation flow values were adjusted to reflect only the Phase I improvements described previously. This analysis indicates that peak flow rates in the sewers in the immediate area of the Hydro Brake controls are generally less than pipe capacity, with a few segments at or slightly above capacity.

It appears that some surcharging will still occur under design storm conditions, particularly in the Phase II areas where controls have not been installed. This is the case in the W. 174th Street-Ponciana-Flamingo area. The Puritas Avenue sewer also exhibits surcharging at all points between W. 174th Street and overflow chamber M-15. It is not known if this condition causes any significant problems in the areas noted.

Evaluation of Control/Retention Sizing

In the early stages of this evaluation, particularly during the Fall, 1980 field monitoring, it became apparent that only the most severe storm events would cause any appreciable response in the control/retention structures. Subsequent review of the original design criteria seemed to indicate that a large percentage of the drainage areas tributary to each retention structure was used in simulating response of the system to a five year design storm. However a significant portion of the runoff from residential sites actually enters the combined sewers directly by way of area drains, footer drains and downspout connections. It appeared that because of an oversight in the original design only roof areas were accounted for in routing flows directly to the sewers.

Once this apparent error had been identified, the City of Cleveland prepared new runoff computations for the drainage areas associated with the W. 170th, W. 177th and Puritas structures (See Appendix F). Given the rainfall pattern employed in the original design, it was determined that a large portion of the subject drainage areas would have to be contributing runoff to be able to generate the peak rates and volumes which were the basis of design of discharge rates and storage volumes.

There are several implications of these findings. It would appear that the storage tanks which had been constructed would rarely be fully utilized, especially up to the five year design level. For the original discharge rates, the storage tanks were apparently significantly overdesigned. Furthermore, if too small a proportion of total runoff were routed to the combined sewers, the available capacity for storm release rate determinations would be too large. Therefore, the Hydro Brake release rates would be too high and could negate the intent to reduce surcharging and basement flooding. Finally, if a smaller proportion of total runoff were actually controlled through the retention structures, combined sewer overflow reduction would be overestimated.

Time constraints and the scope of this evaluation did not allow computer simulation of system hydraulics to check the validity of these concerns, nor was it possible to observe these effects in the field beyond the noted lack of response of the control/retention structures to significant rainfall events. No storms resembling a five year design storm were recorded, and it was not possible to estimate the response of the combined sewers receiving storm flows.

HYDRO BRAKE REDESIGN

Design Concept

After the Fall, 1980 monitoring period, during which insufficient amounts of data were collected, the City of Cleveland initiated a project to redesign the Hydro Brake discharge rates at the three retention structures. The intent of the redesign effort was to define runoff parameters for representative design storms having various durations and return periods, and to reduce the Hydro Brake discharge rates such that the storage facilities would have a more frequent, higher percentage utilization in relation to these storms. A discussion of this effort has been prepared by the City of Cleveland and is included in Appendix F.

Design Criteria

The areas which drain directly to the control/retention structures were defined as the area between building set back lines, which includes streets, sidewalks, driveways, treelawns and front yard areas. These areas are presented in Table 1, Section 5. A runoff coefficient of .5 was used with a time of concentration of 25 minutes (See Appendix F). Rainfall distributions representative of the Cleveland area were used in defining runoff parameters.

Hydro Brake Sizing

Runoff volumes were calculated and inflow hydrographs were constructed for each location. Hydro Brake discharge rates were selected which maximized storage of five and ten year design storms while maintaining a safe level of control over surface flooding. Table 5 presents a comparison of original design and redesign Hydro Brake discharge rates.

TABLE 5. COMPARISON OF HYDRO BRAKE DISCHARGE RATES

Location	Original Design Discharge Rate cfs	(L/s)	Redesign Discharge Rate cfs	(L/s)
W. 170th Street	2.0	(57)	1.25	(35)
W. 177th Street	1.5	(42)	.25	(7.1)
Puritas Ave.	7.0	(197)	1.00	(28)

The new control devices were to be delivered and installed prior to the start of the Summer, 1981 monitoring period. Various delays in delivery of the new Hydro Brakes and their installation postponed operations under redesign conditions until July, 1981. Therefore, data collection during 1981 represents "before" and "after" redesign.

EVALUATION OF HYDRO BRAKE REDESIGN

Combined Sewer Overflow Reduction

It was assumed that the combined reduction of 8.0 cfs (226 L/s) in Hydro Brake discharge rates would result in a reduction of peak inflow rates to 81 cfs (2294 L/s) at overflow chamber M-15. From comparisons with values in Table 4, the estimated peak overflow rate is 69 cfs (1954 L/s) with an overflow volume of 106,400 ft.^{3} (3013 x 10^3 L). This represents an estimated 37% reduction in the peak rate of combined overflow over the previous conditions of no stormwater control. Overflow volume reduction is estimated at 44%.

Reduction in Flooding and Surcharging

By reducing Hydro Brake discharge rates, it was expected that flow rates in the receiving combined sewers should be reduced by a similar amount. It was not possible to determine from survey results whether this difference would be noticed by homeowners when compared to prevailing conditions with the original Hydro Brakes.

As noted previously for the original design Hydro Brakes, no surcharging in the vicinity of the control devices is apparent when the sewer system simulation results are examined. As indicated above, this condition should be further improved with lower rate devices in place. Those sewers on Puritas Avenue and W. 174th Street, which would apparently be surcharged under design conditions with the original Hydro Brakes in place, would still be surcharged but to a lesser degree.

With the redesigned Hydro Brakes in place, it is also expected that the potential for surface ponding during severe storm events is somewhat increased. An evaluation of design storm conditions presented below indicates that any surface flooding which might occur will be relatively minor.

Evaluation of Redesigned Hydro Brake Devices Using Storm Simulation Techniques

In an effort to evaluate the performance of the redesigned Hydro Brake control/retention structures in relation to design storm conditions, storm hydrographs and runoff volumes were calculated using the design criteria proposed by the City of Cleveland and the hydrograph construction methods presented in Section 4. As noted previously, one-half hour duration storms were used because they would generate the highest peak flow rates over the drainage areas of interest. This was done to illustrate the highest probable level of control (i.e. peak rate attenuation) that could be provided by the Hydro Brake control devices. However, larger storage volume requirements are possible from longer duration storms having the same return frequency as the 1, 2, 5 and 10 year storms examined.

After construction of inflow hydrographs, discharge hydrographs were computed using the storage continuity relationship presented in Section 4. These calculations were performed for the original Hydro Brake discharge rates for comparison with design values, and for the redesigned discharge rates in order to project the expected performance of these units. The head-discharge curves used were the calculated relationships from the field calibration tests of each Hydro Brake device. Hydrographs are presented in Appendix E.

Table 6 summarizes rainfall parameters for the one-half hour duration storms examined.

TABLE 6. DESIGN HYDROGRAPH PARAMETERS - 1/2 HOUR STORM RAINFALL AND INTENSITY

Storm Return Frequency	Total Rainfall		Peak Intensity	
	in.	(cm.)	in/hr.	(cm/hr)
1	.76	(1.93)	4.0	(10.2)
2	.91	(2.31)	4.7	(11.9)
5	1.19	(3.02)	6.2	(15.7)
10	1.37	(3.48)	7.1	(18.0)

Table 7 presents comparisons of Hydro Brake discharge rates and required storage volumes for a five year design storm as computed by simulation during the original design and by methods employed in this evaluation. Note that the drainage areas and design storms used in the two methods are not equivalent.

TABLE 7. COMPARISON OF HYDRO BRAKE DISCHARGE RATES AND STORAGE VOLUMES FOR 5 YEAR DESIGN STORMS

	Original Design					
	Peak Inflow Rate		Peak Discharge Rate		Storage Required	
Location	cfs	(L/s)	cfs	(L/s)	ft^3	(1000 L)
W. 170th Street	4.3	(122)	2.0	(57)	3,750	(106)
W. 177th Street	5.8	(42)	1.5	(42)	10,230	(289)
Puritas Avenue	13.0	(368)	7.0	(198)	6,270	(178)

	Post-Construction Evaluation					
	Peak Inflow Rate		Peak Discharge Rate		Storage Required	
Location	cfs	(L/s)	cfs	(L/s)	ft^3	(1000 L)
W. 170th Street	3.4	(96)	3.1	(88)	380	(11)
W. 177th Street	4.4	(125)	1.7	(48)	3,470	(98)
Puritas Avenue	5.0	(142)	7.0	(198)	None	--

Table 8 presents a summary of the expected performance of the control/retention structures for various one-half hour design storms with the redesigned Hydro Brake devices in place. It is projected that storage capacity would be exceeded at the W. 170th Street structure for the 5 and 10 year return storms. For the 5 year storm, there would be 340 ft^3 (9630 L) and for the 10 year storm, a 930 ft^3 (26,340 L) of stormwater in excess of storage capacity. For surface ponding at an average depth of 4 inches (10 cm) on a 24 foot (7.3 M) wide road surface, flooding would occur over a distance of 42 feet and 116 feet (12.8 m and 35.4 M), respectively, and drain down at the indicated peak discharge rates would occur in 4.5 and 11.5 minutes. This condition appears to be of minor consequence considering that it would rarely occur and is of very short duration.

TABLE 8. SUMMARY OF HYDRO BRAKE CONTROL/RETENTION FOR 1/2 HOUR DURATION DESIGN STORMS

Control Structure Location	Design Storm Return Period	Peak Inflow (Runoff) Rate To Retention cfs	(L/s)	Peak Discharge Rate cfs	(L/s)	Retention Inflow Volume ft^3	(1000 L)	Storage Volume Required ft^3	(1000 L)	Percent Storage Utilization
W. 170th St.	1	2.15	(61)	1.12	(32)	3,340	(95)	1,280	(36)	55
	2	2.58	(73)	1.19	(34)	3,940	(112)	1,690	(48)	75
	5	3.40	(96)	1.30	(37)	5,220	(148)	2,640	(75)	115
	10	3.90	(110)	1.35	(38)	6,000	(170)	3,230	(91)	140
W. 177th St.	1	2.80	(79)	.43	(12)	4,280	(121)	3,350	(95)	35
	2	3.35	(95)	.45	(13)	5,130	(145)	4,120	(117)	40
	5	4.38	(124)	.48	(14)	6,670	(189)	5,550	(157)	60
	10	5.10	(144)	.50	(14)	7,730	(219)	6,540	(185)	70
Puritas Ave.	1	3.17	(90)	1.78	(50)	4,810	(136)	1,570	(44)	25
	2	3.78	(107)	1.89	(54)	5,800	(164)	2,220	(63)	35
	5	4.96	(140)	2.05	(58)	7,700	(218)	3,570	(101)	60
	10	5.70	(161)	2.12	(60)	8,710	(247)	4,430	(125)	70

SECTION 7

COMPARATIVE EVALUATION OF FLOW REGULATOR INSTALLATIONS

Flow regulator devices have been used and evaluated in several communities in the United States and Canada. Evaluations have included emperical observations vs computer simulated performance of Hydro Brake devices, and evaluations of such devices compared to straight orifice reduction, as well as evaluation against uncontrolled discharge.

Applications varied, as did the sizes of drainage areas and the types of unit configuration.

PROJECT SUMMARIES

Rochester, New York (4)

In Rochester, an off-line storage tank for stormwater retention was constructed for comparative evaluation purposes. A Hydro Brake Standard 5-B-7 unit and a three-inch (75 mm) orifice were tested under controlled head conditions. A variable head test and a static head test were run for each. Unfortunately, size and rating data were not available for the Hydro Brake, making comparison of results something of a matter of faith.

Head-discharge curves demonstrated that the Hydro Brake device successfully retarded the discharge rate as heads increased. The observed orifice discharge rate was nearly in linear relationship to the head, as would be expected; for a simple orifice, flow rate is proportional to the square root of the head. The Hydro Brake discharge rate tended strongly to be asymptotic in relationship to the head. Figure 19, redrawn from O'Brien and Gere, demonstrates th edischarge curves. Figure 20 illustrates the relationship between discharge rates derived during testing and discharge rates as described by the manufacturer. The difference is attributable to experimental error, when compared to the difference between the Hydro Brake and the three-inch orifice, according to the study report.

Additionally, the performance of the Hydro Brake during a storm, which occurred fortuitously during the testing period, was evaluated. Inflow and outflow were monitored and plotted, (Figure 21), demonstrating that the Hydro Brake effectively retarded peak flows and maintained relative discharge constancy throughout the discharge period.

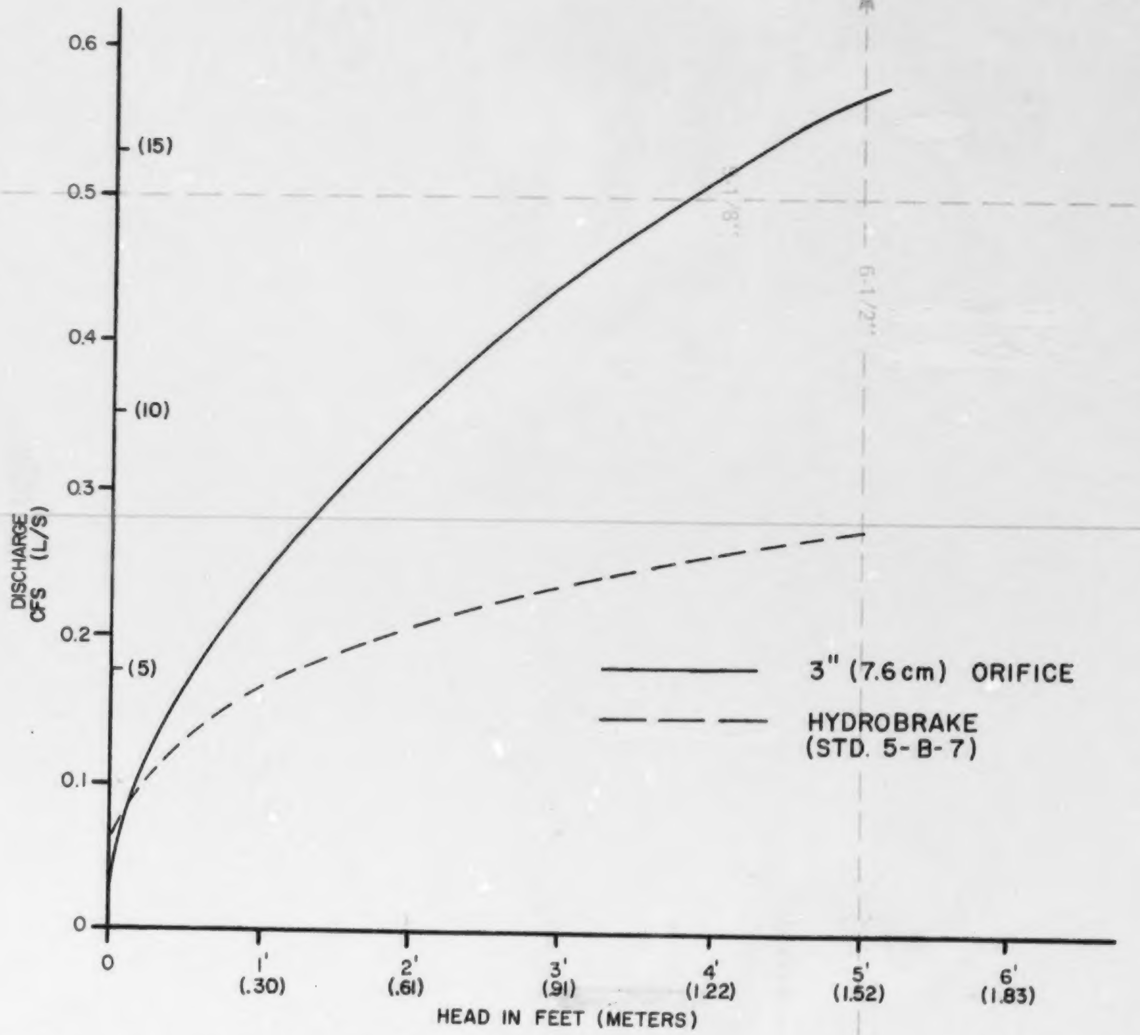

FIGURE 19 HEAD – DISCHARGE CURVES SANTEE DRAINAGE AREA CALIBRATION

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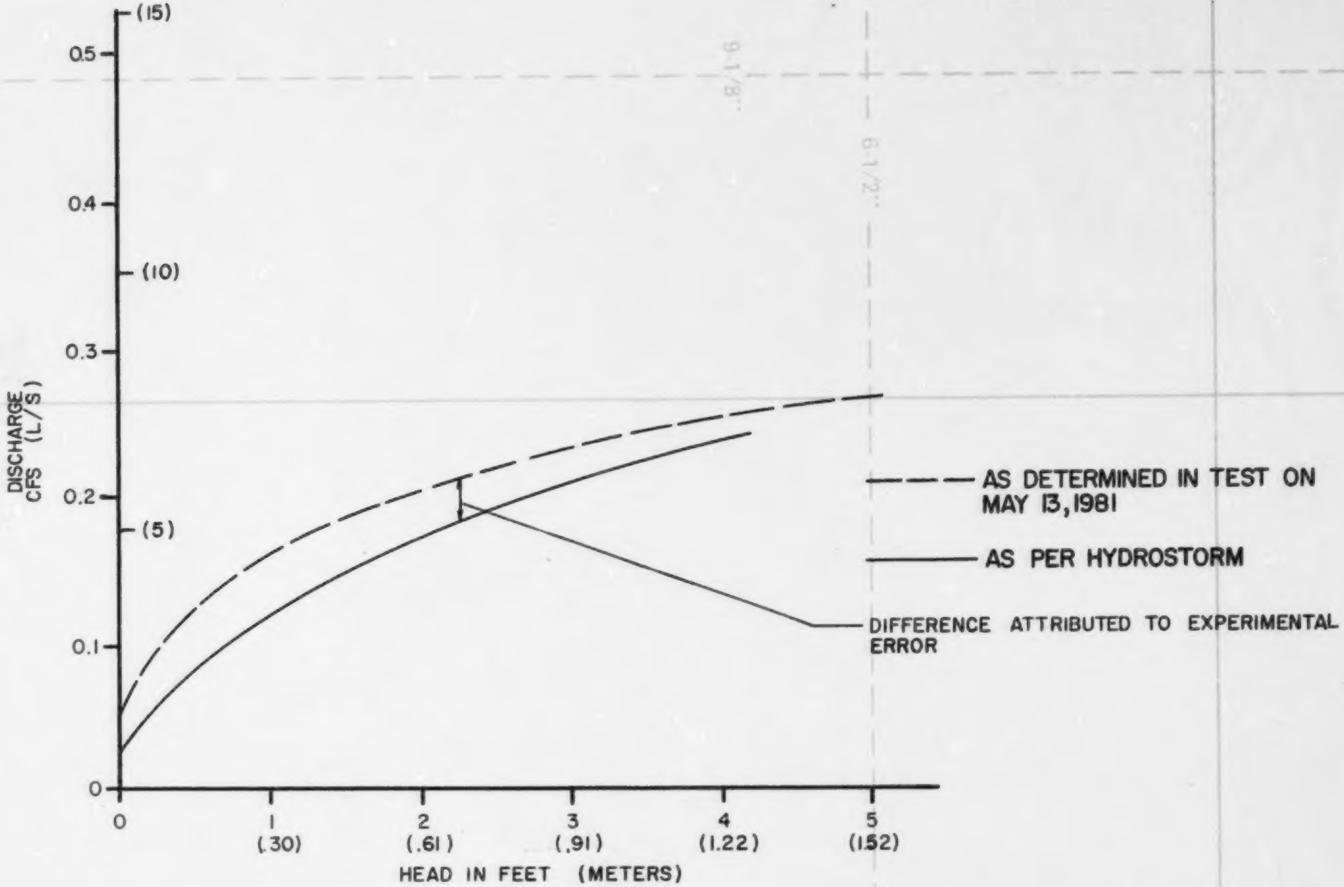

FIGURE 20 HEAD-DISCHARGE CURVE, SANTEE HYDROBRAKE

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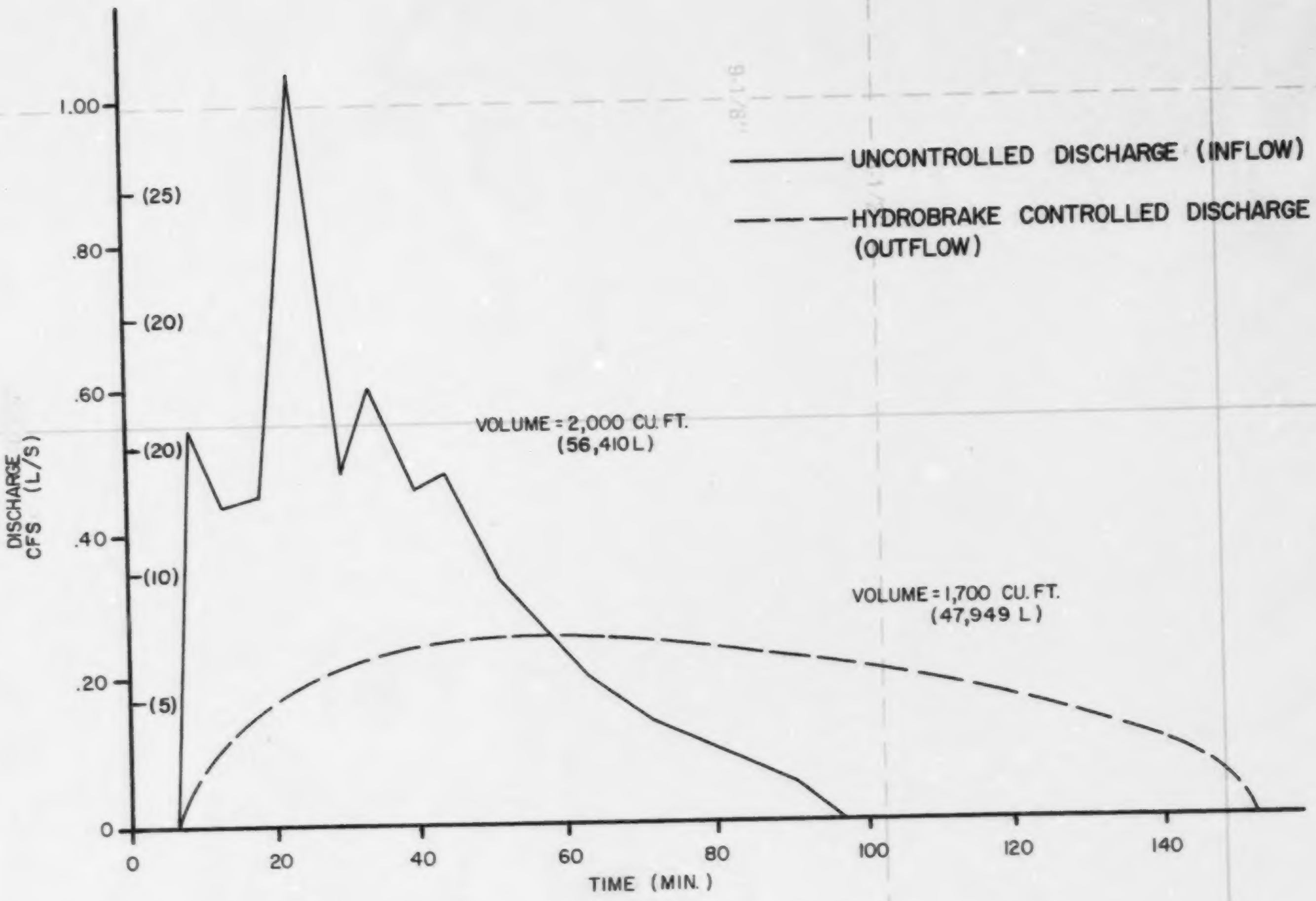

FIGURE 21 STORM OF MAY 11, 1981 — SANTEE DRAINAGE AREA

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Toward the end of this study, it was noted that the Standard 5-B-7 Hydro Brake was showing discharge curves that were not appreciably different from an orifice of similar diameter. Debris in the entry slot was discovered to be the cause. Although the piece of lath had not blocked the flow, as had the styrofoam cup in the W. 177th Street (Cleveland) installation, it had affected the flow regulating characteristics of the unit.

The Rochester, New York, application of the Hydro Brake parallels the Cleveland project. The Rochester demonstration project report is presented in Appendix G to provide supplemental information pertinent to the application of this technology.

Nepean Township, Ottawa, Canada (5)

This evaluation consisted of the installation of two oversize catch basins, in which Hydro Brakes were installed. One catch basin drained 1.28 acres (0.519 ha), of which .39 acres (0.158 ha) was 86.67 ft^3 (2,450 L) and was outfitted with a Hydro Brake of 0.6 in. (15 mm) diameter orifice.

The other catch basin drained 0.61 acres (248 ha), of which 0.34 acres (0.139 ha) was impervious surface. This basin contained a storage capacity of 75.6 ft^3 (2,135 L) and was outfitted with a Hydro Brake of 2.0 in (50 mm) diameter orifice. Water levels in the catch basins were monitored by means of continuous recording water level sensing units. Outflow was calculated from the water level and rainfall data by first calculating inflow, and then using discharge curves supplied by the manufacturer, deriving discharge volumes.

The Hydro Brakes demonstrably attenuated the peak flows (Figures 22, 23, 24, 25, and 26, redrawn from Gore and Storrie), but the 0.6 in (15 mm) diameter device proved to be too small for the storage volumes provided. It was replaced with a 4.0 in (100 mm) device, but storm events during the study period did not produce great enough peak flows to exceed this unit's pass-through capacity. Table 9 shows the peak flow reductions obtained by the 2.0 in (50 mm) device for several storms. As was the case in Cleveland, accurate sizing of Hydro Brake devices during design proved to be a problem.

No problems with debris in regards to Hydro Brake operation were reported in this study. However, it was noted that solids buildup in the catch basins did occur, and that odor was a problem. Attempts to trap solids in mesh bags were unsuccessful.

TABLE 9 ANALYSIS OF PEAK FLOW ATTENTUATION FOR 2 IN. UNIT

Storm Event	Peak Rate of Runoff L/s	Peak Rate of Runoff cfs	Attenuated Peak L/s	Attenuated Peak cfs	% Reduction of Peak
May 23, 1977	5.60	.198	1.20	.042	78.5
May 28, 1977	2.94	.104	1.05	.037	64.3
June 25, 1977	2.95	.104	0.85	.030	71.2
June 29, 1977	.12	.145	1.10	.039	73.3
July 1, 1977	6.20	.219	1.17	.041	81.1

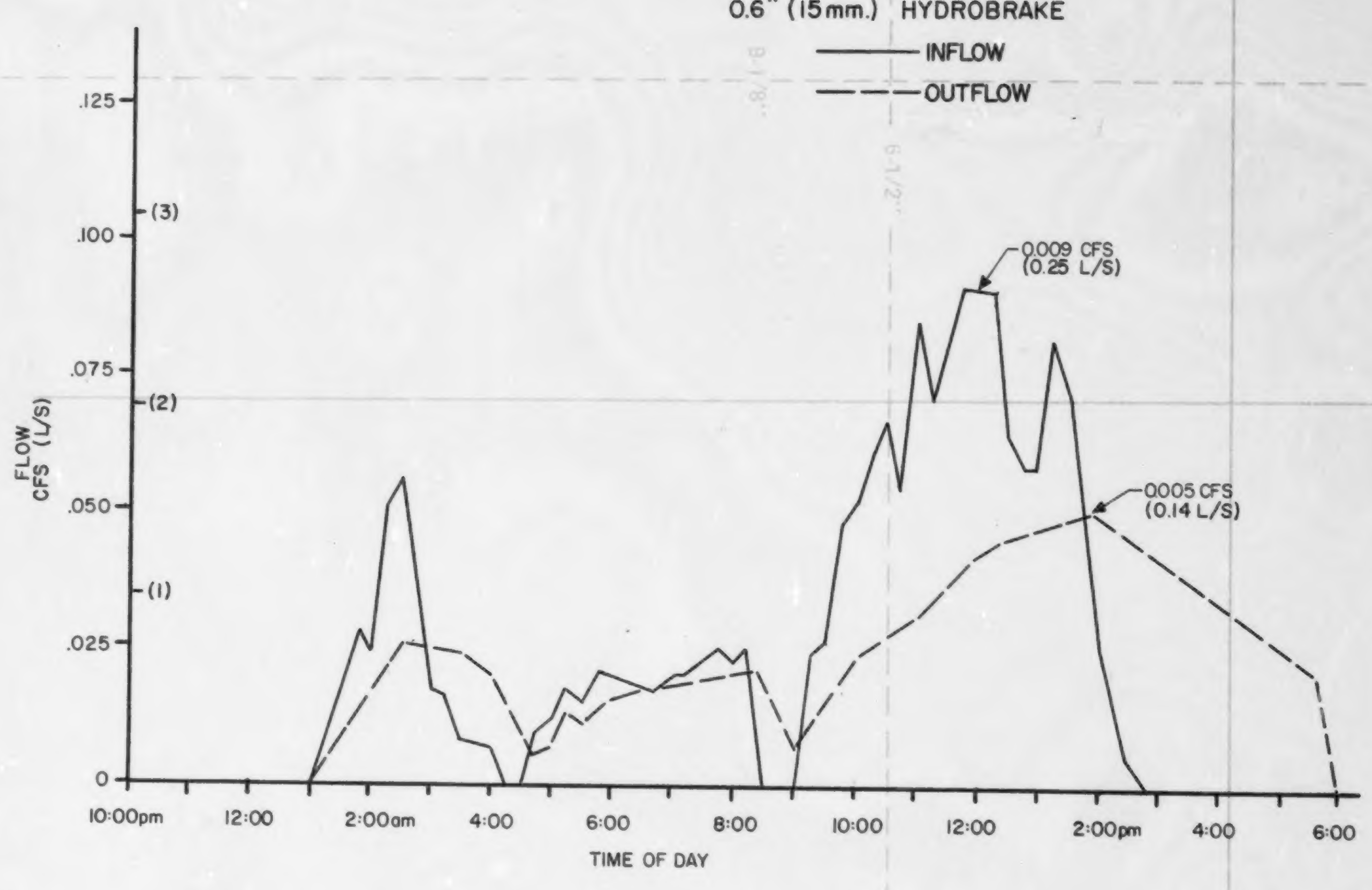

FIGURE 22 INFLOW—OUTFLOW HYDROGRAPHS NEPEAN TWP. AREA I — OCTOBER 30/31, 1976

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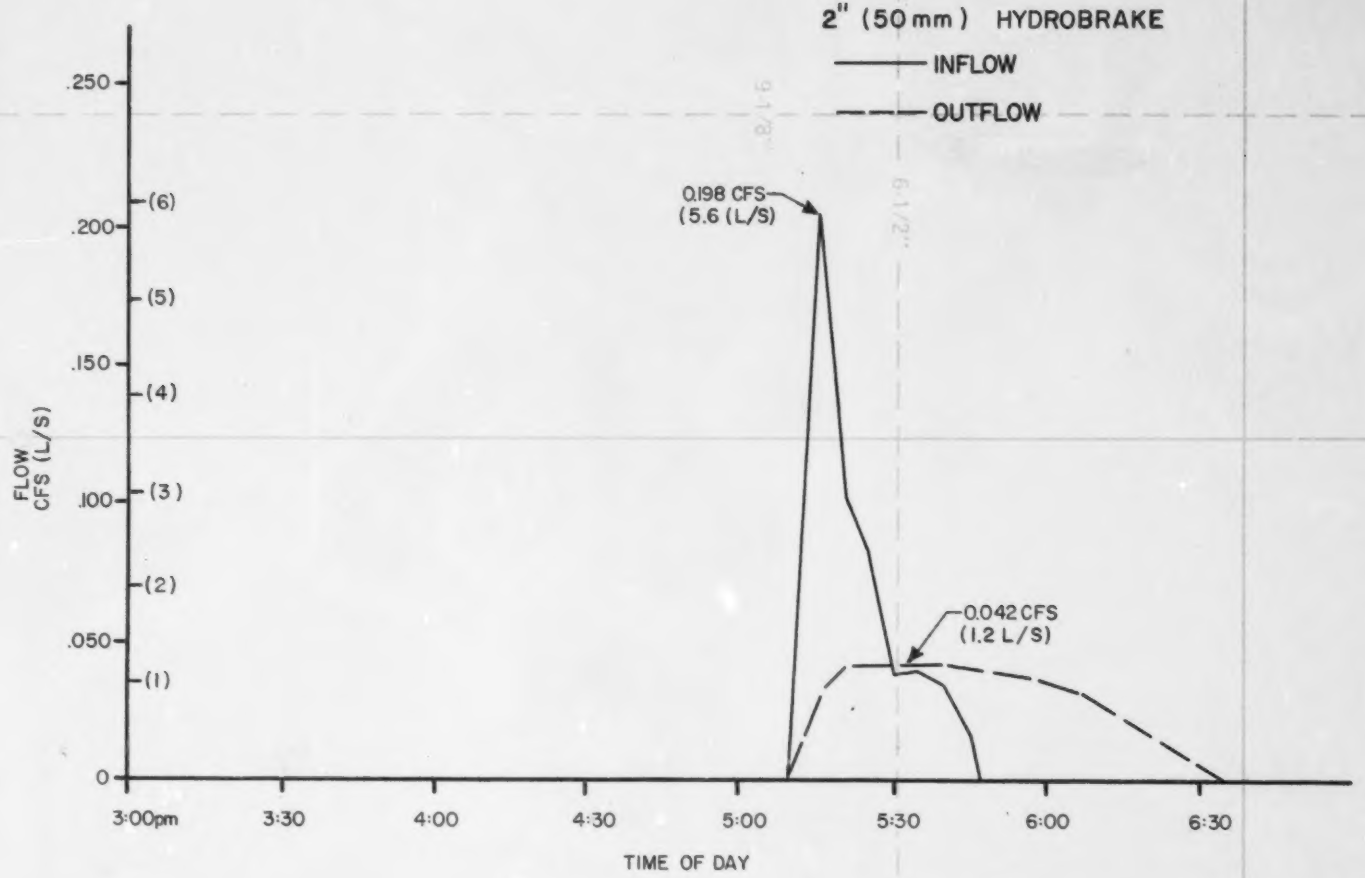

FIGURE 23 INFLOW—OUTFLOW HYDROGRAPHS NEPEAN TWP. AREA 2 — MAY 23, 1977

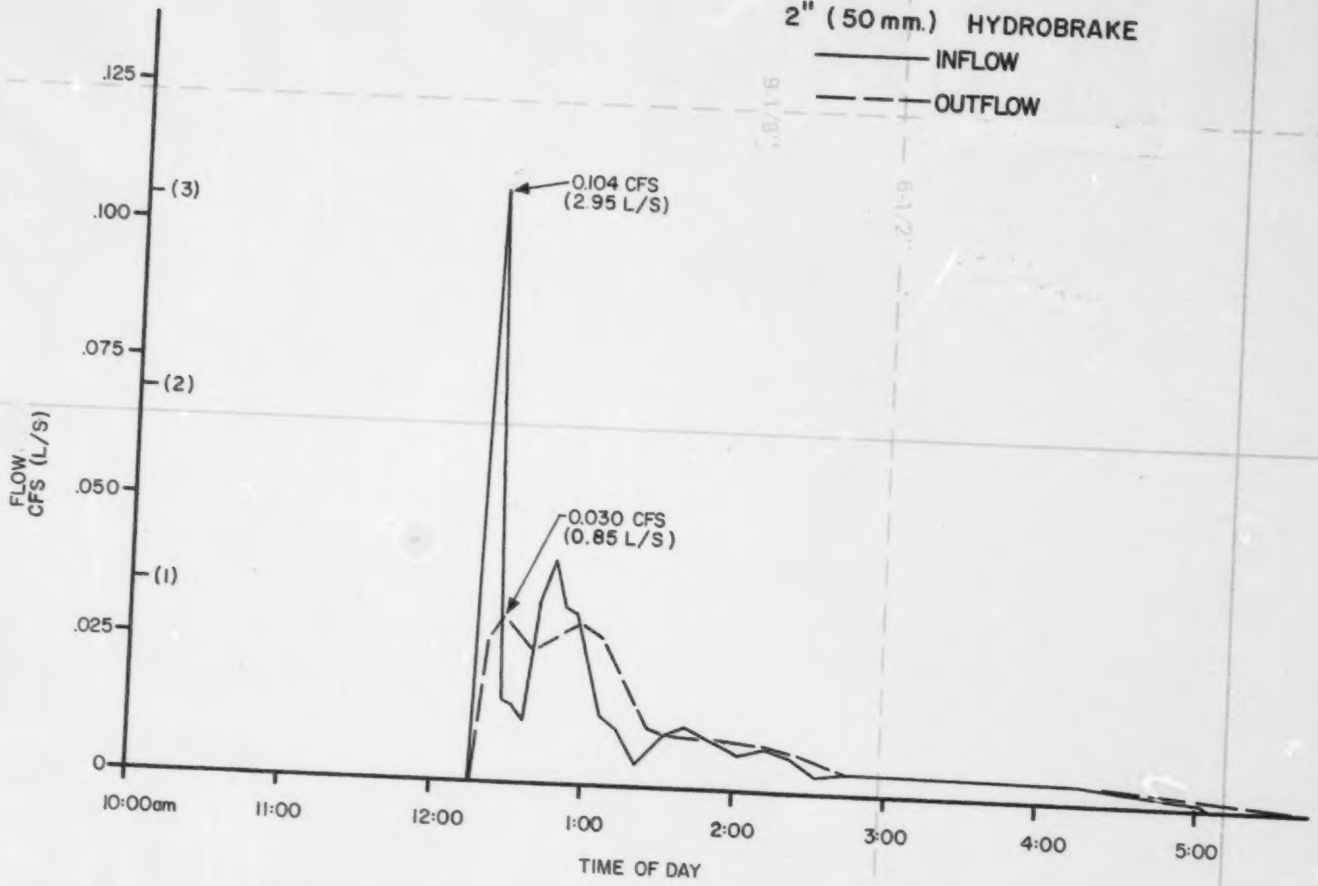

FIGURE 24 INFLOW—OUTFLOW HYDROGRAPHS NEPEAN TWP. AREA 2 JUNE 25, 1977

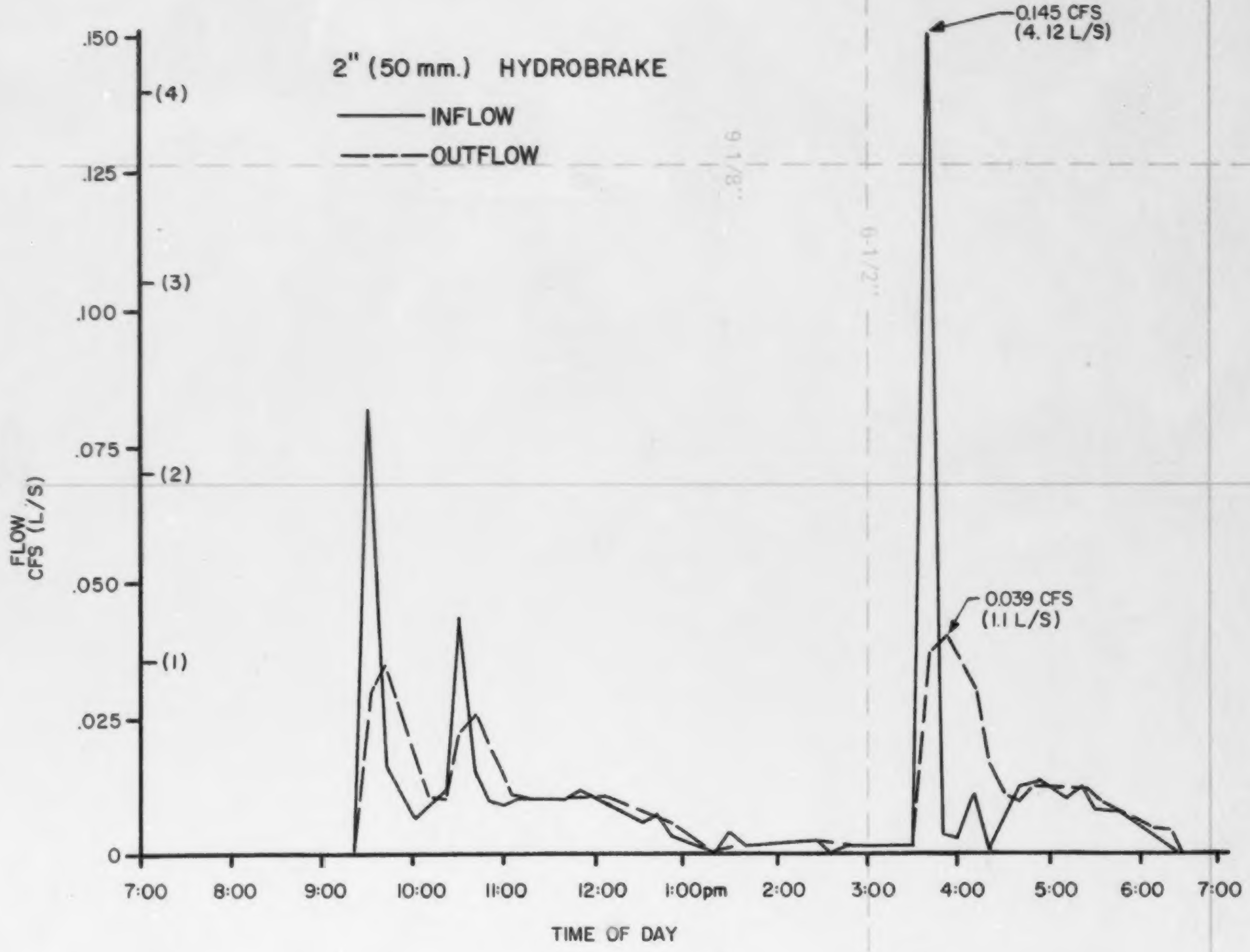

FIGURE 25 INFLOW-OUTFLOW HYDROGAPHS NEPEAN TWP. AREA 2 JUNE 29, 1977

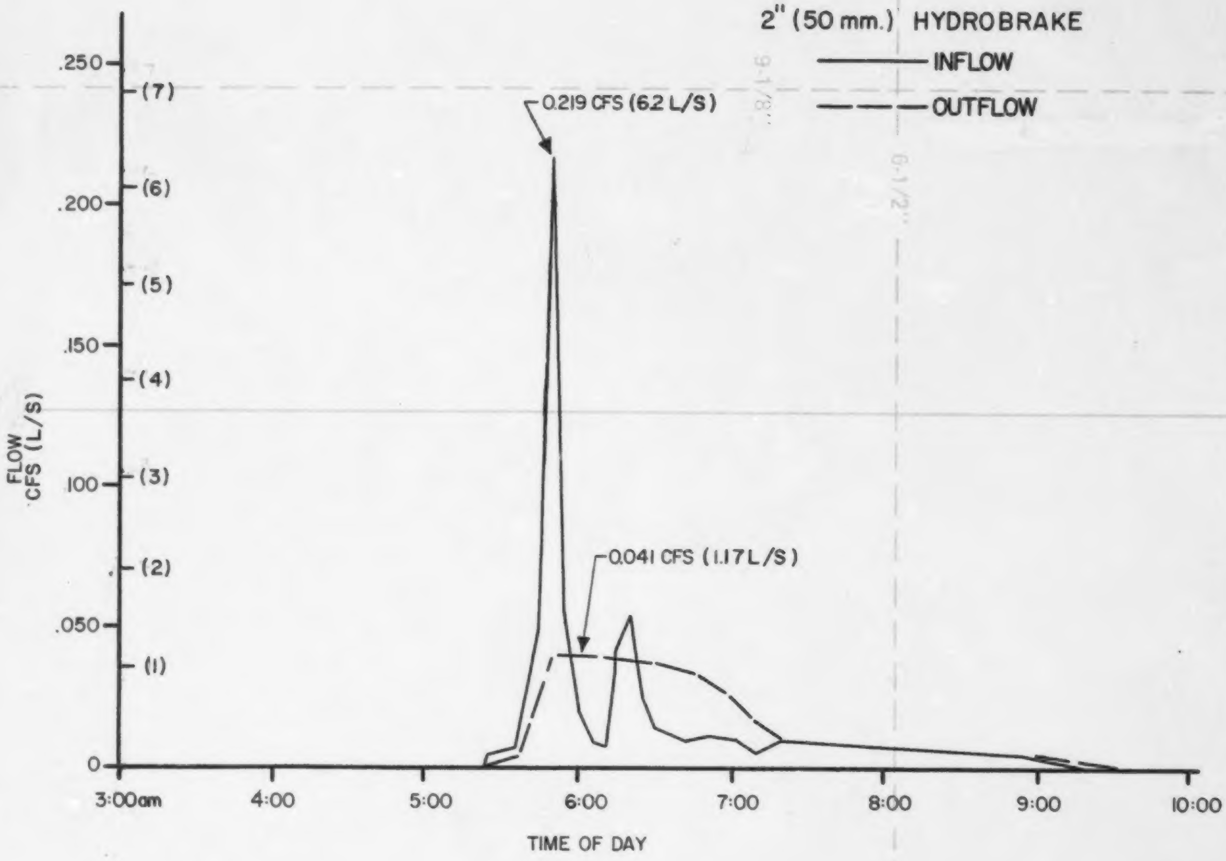

FIGURE 26 INFLOW—OUTFLOW HYDROGRAPHS NEPEAN TWP. AREA 2 — JULY 1, 1977

Borough of York, Ontario, Canada (6)

This study does not include evaluations of Hydro Brakes *in situ*. Rather, it uses as a given the ability of the device to regulate flow to a desired maximum discharge. Based upon that ability, four areas of the Borough of York are evaluated.

The results of those evaluations were translated into required storage capacities and regulated discharge rates for each area, presented for 2, 5 and 10 year frequency storms. Discharge rates are calculated from runoff coefficients and existing sewer capacities to provide zero surcharge flow in existing sewers.

Hydro Brake installation in the four areas is expected to permit the existing sewers to carry the design flow without system modification other than construction of off-line storage, or implementation of roof storage in one industrial area.

Euclid, Ohio

Although no formal evaluation of the effectiveness of the City's Hydro Brake installations has been performed, telephone interviews with Mayor Anthony Giunta and Mr. John Piscitello, Service Director, elicited some information. Hydro Brakes were installed directly in catch basins in areas which experience basement flooding, in effect utilizing street retention of storm waters upstream of flooded areas. Both the Mayor and the Service Director feel that the devices have worked well, and that flooding problems have been greatly reduced, albeit not entirely eliminated.

COMPARISON OF INSTALLATIONS

Introduction

Comparisons among the Hydro Brake installations described above and between those and the Cleveland installation are difficult. Hard data is, for the most part, extremely limited in the few reports published to date. Although results are ascribed to various factors, it is not possible to compare their derivations, since such basic data as Hydro Brake orifice diameter, calibration of storage structures, discharge calibration, etc. are each missing from one or another of the reports. Much of this lack of data is probably ascribable to the fact that the reports available are intended to apprise a client of results, rather than to qualify the report for journal publication.

In addition, each installation is different from the others, and only the Santee Drainage Area in Rochester, New York, installation is similar to the Cleveland project.

Finally, although Hydro Brakes have apparently been installed in at least a dozen locations, follow-up studies are, for the most part, unavailable. Thus, quantitative evaluations and comparisons are limited to only those described above.

Discussion of Calibration

The Rochester, New York installation is most similar to the Cleveland project. An underground, off-line storage structure with a Hydro Brake regulator was installed to accept the flow from approximately 50,000-55,000 ft^2 (.465-.512 ha) as compared to the Cleveland installations. Those installations drained approximately three acres (1.215 ha) each. The Cleveland falling head calibrations of Hydro Brake discharge were, in fact, modeled after the Rochester study. Unfortunately, physical problems with the sewer plugging efforts limited the usefulness of some of the results (see Section 4). However, it was noted that the discharge curves that were developed did not indicate so dramatic a flow attenuation as did the discharge curve developed in Rochester.

Figure 27 displays the Cleveland calibration curves against the Rochester calibration curve for the Hydro Brake Standard 5-B-7. Although various sizes of Hydro Brakes are included, a consistent pattern of attenuation (discharge independent of head) should be evident for all. As can be seen, this seems to be the case. However, as shown in Table 10, (which includes data from the Nepean Twp. Ottawa Project) local conditions may affect Hydro Brake performance.

As can be seen, observed flow rates in the Nepean Twp. and Rochester studies more closely approximated the expected rates than did the observed Cleveland rates. The 1.0 cfs (28.3L/s) and 2.0 cfs (26.6 L/s) units in the Cleveland study units were especially high in relationship to the expected flows. The difference shown for the 2.0 cfs (56.6 L/s) unit is not explainable by available data, although the leakage described in Section 4 may have contributed significantly. In any case, it is apparent that some attenuation of flow occurs for all sizes of Hydro Brake.

The Nepean Twp. installations were somewhat different from the Cleveland and Rochester installations, in that the storage volume provided was much less per unit area of drainage. However, if street storage is assumed equivalent to off-line storage, the ultimate function of the units is quite similar. Calibration data is included in Table 10, but the flows were too low to be effectively displayed in Figure 27.

Discussion of Rainfall Event Monitoring

Although differences in monitoring and calculation methodologies among the studies make quantitative comparisons unuseable, it is apparent that in Rochester, Nepean Twp. and Cleveland, the Hydro Brakes did reduce peak flows. Thiseeffect in turn increased storage; thereby delaying entry of stormwater into the sewer system. Therefore, it can be said that in all three cases, additional sewer capacity was made available during the monitored storm events. Comparative flow rate analyses of ordinary orifices,

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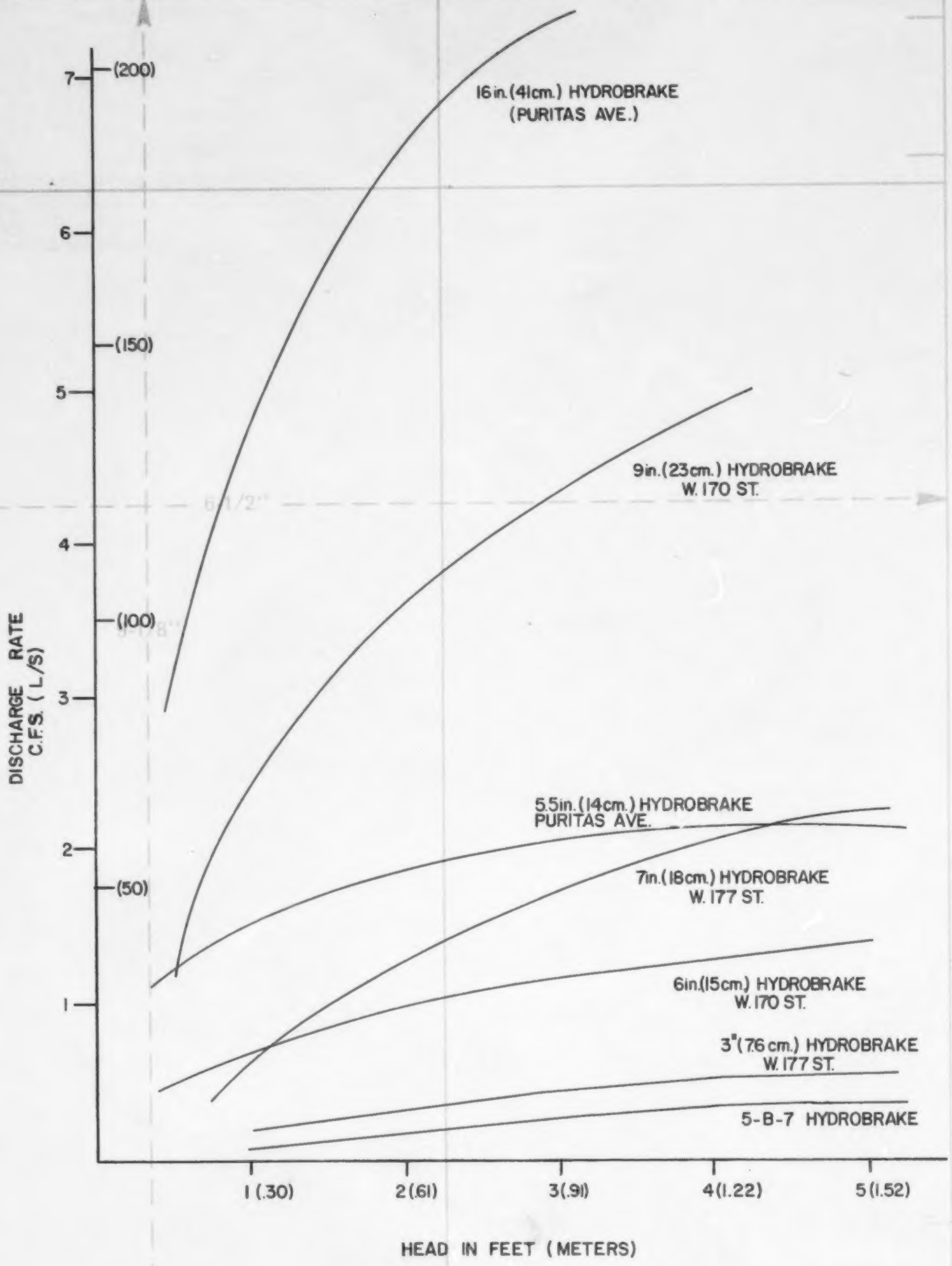

FIGURE 27 COMPARISON OF HYDROBRAKE DISCHARGE CURVES

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TABLE 10

COMPARISON OF RATED AND ACTUAL HYDRO BRAKE DISCHARGES

Hydro Brake Size in.	(cm)	Manufacturer's Rating (cfs) cfs	L/s	Observed Flow (cfs) at 3 ft. Head cfs	L/s	Observed Flow (cfs) at 5 ft. Head cfs	L/s	Location
.6	(1.52)	.005	(.142)	.006	(.17)	--	--	Nepean Twp.
2.0	(5.08)	.05	(1.42)	.04	(1.13)	--	--	Nepean Twp.
3.0	(7.62)	.24	(6.80)	.21	(5.95)	.27	(7.65)	Rochester
3.0*	(7.62)			.44	(12.46)	.58	(16.42)	Rochester
3.0	(7.62)	.25	(7.08)	.40	(11.53)	--	--	Cleve./W. 177
5.5	(13.97)	1.00	(28.32)	2.95	(83.54)	3.95	(111.86)	Cleve./Puritas
6.0	(15.24)	1.25	(35.40)	1.30	(36.81)	1.45	(41.06)	Cleve./W. 170
7.0	(17.78)	1.50	(42.48)	1.85	(52.40)	2.50	(70.80)	Cleve./W. 177
9.0	(22.86)	2.00	(56.64)	4.40	(124.60)	5.50	(155.75)	Cleve./W. 170
16.0	(40.64)	7.00	(198.23)	7.70	(218.05)	9.10	(257.70)	Cleve./Puritas

*Straight Orifice

similar in size to the Hydro Brake devices, strongly suggest that the Hydro Brakes were able to retard flow, using a larger outlet than would have been possible with a standard orifice.

In addition ,the Cleveland study indicates that by making additional sewer capacity available, basement flooding and some street flooding was reduced. The City of Euclid reports apparently similar results. By the use of Hydro Brakes in catch basins, Euclid utilizes street storage, thus reducing catch basin surcharging, and consequently basement flooding caused by back-up flows from those catch basins.

In summary, it would seem that the method of storage is relatively unimportant. As suggested in the study prepared for the Borough of York, street, roof and parking lot, or buried off-line tank storage should be determined from the uses and needs of the project area; with the Hydro Brakes designed to best serve the chosen storage method.

The Hydro Brakes themselves seem to have two outstanding advantages. By retarding flow while permitting a larger outlet, they seem less likely to become fouled by refuse than would the smaller orifice. However, as demonstrated by the redesigned 177th Street Hydro Brake in Cleveland, small orifice Hydro Brakes may themselves become fouled. This does not negate the likelihood that the even smaller orifice required for the same level of control would incur a proportionately greater risk of fouling. In addition, their flexibility of design allows for a variety of applications, which increase their attractiveness as control devices for older, overloaded sewer systems that may otherwise require the alternatives of replacement or relief sewer construction.

Debris in two Hydro Brakes affected performance. In the W. 177th Street installation (Cleveland), a styrofoam cup wholly blocked the flow of stormwater. In the Standard 5-B-7 installation (Rochester) a piece of lath apparently interrupted the vortex within the unit, and thereby permitted stormwater flow to occur at a rate equal to a 3.5 in (8.9 cm) orifice.

Generally speaking, maintenance was not described as a problem, although the Nepean Township catch basin installations were subject to solids depositions. Regular clean-out was necessary because of odors.

SECTION 8

ALTERNATIVE EVALUATION

GENERAL SCREENING OF ALTERNATIVES

Some alternatives for alleviating detrimental combined sewer overflow effects are not practical for handling upstream sewer surcharge problems. These control methods were identified and eliminated from further consideration.

Combined Sewer Relief Regulators

This method of alleviating combined sewer overloads is not viable in areas similar to the Puritas Avenue study area. There is no where to relieve the combined sewers without extensive interceptor construction, and this option compounds the health and water quality degradation problems of conventional combined overflows.

In-Line Storage

Where there is available trunk and interceptor capacity, this is a simple, cost-effective means of controlling storm flows through in-line regulators. There is no excess capacity in the sewers of the subject study area.

End of Pipe Methods

Interception and transportation of combined flows at the point of overflow does not relieve surcharging upstream of the control point, and requires large interceptor construction to carry flows to some point for treatment. Likewise, end of pipe treatment does nothing for problems upstream and usually has lower pollutant removal efficiencies compared with centralized treatment facilities. Controls in upstream problem areas reduce the pressure on downstream control points, in large part eliminating the need for peak flow rate transportation or treatment.

Off-Line Combined Storage with Gravity Discharge

Grades in the study area are not sufficient to allow a workable gravity influent/gravity effluent combined flow storage approach. To take advantage of gravity return from off-line storage here would require high capacity lift stations capable of handling peak runoff rates. The reliability of such a system would also be jeopardized by power outages, so that back-up power would also be requird.

DESCRIPTION OF VIABLE ALTERNATIVES

Inlet Control

The simplest control requires only regulation of peak flows at combined sewer inlet points. Hydro Brake control devices inserted in catch basins has been successfully implemented in several areas, as noted in Section 7. This option is contingent upon the availability and safety of surface ponding to accommodate storm water storage requirements.

Inlet Control and Storage

This alternative is the central issue of this evaluation. A combination of inlet controls and below grade storage was used for storm flow regulation. Relatively shallow storage facilities are required to allow gravity discharge to the combined sewers. This approach offers considerable design and flow regulation flexibility, depending on the level of control desired.

Off-Line Combined Storage with Pumped Discharge

Storage facilities must be deeper than the combined sewers, and require pumping to return flows to the collection system. Storage volume and flow regulation rates are flexible, with the pump discharge being the flow rate control mechanism. Compared to surface runoff storage, combined flow storage may have higher maintenance requirements because of solids deposition and decomposition problems.

Sewer Separation

This option eliminates combined sewers but only with very extensive construction and at great expense. Sewer construction in fully developed urban areas is often beyond the means of both residents and public agencies.

COST ESTIMATES OF VIABLE ALTERNATIVES

Project cost summaries have been compiled from the City of Cleveland's project cost summaries for the Puritas Avenue and Milburn Avenue projects, the Santee Drainage Area/Hydro Brake Demonstration Project report (O'Brien & Gere) (7) and EPA construction cost summaries. All costs were adjusted to an ENR index of 3700 (January, 1982) and are reported as cost per acre for rough comparability, although project scales are different.

For estimation of off-line combined flow storage costs, it was assumed that one retention dewatering lift station rated at 0.5 - 1.0 cfs (14 - 28 L/s) would be required for a 10 acre (4 ha) drainage area. The only difference between the Hydro Brake storage tanksand the combined flow storage is depth; costs were based on Hydro Brake storage costs plus 25%.

Table 11 presents a comparison of the costs for the various alternatives discussed. The obvious benefit of the Hydro Brake concept is its cost-effectiveness when compared with other alternatives.

TABLE 11. COST COMPARISONS OF STORM FLOW CONTROL ALTERNATIVES

		Drainage Area		Cost Per	
Alternative	Project Cost	Acres	(hectares)	Acre	($/hectare)
Inlet Control (Cleveland)	$ 4,300	31	(12.5)	$ 140	($350)
Inlet Control & Storage (Cleveland)	$345,000	25	(10.1)	$13,800	($34,200)
Inlet Control (O'Brien & Gere)(7)	8,400	35	(14.2)	$ 240	($590)
Inlet Control Storage (O'Brien & Gere)(7)	$22,100	1.25	(.5)	$17,700	($44,200)
Combined Storage					
(a) Retention		1	(.4)	$13,500	($33,300)
(b) Pumping		1	(.4)	8,500	($21,000)
(c) TOTAL		1	(.4)	$22,000	($54,300)
Sewer Separation		1	(.4)	$30,000-45,000	(74,100-111,000)

REFERENCES

1. Theil, Paul E., and A.M. Candaras, Paul Theil Associates Limited, Design of the Hydro Brake Stormwater Detention Tank Assemblies for the Control of Combined Sewer Overflow Pollution, EPA Demonstration Grant No. S005370, April, 1981. (unpublished in-file report).

2. Chien, Jong-Song, and K.K. Saigal, Urban Runoff by Linearized Subhydrographic Method. Journal of the HYD. Div., ASCE, HY 8, Aug., 1974.

3. Terstriep, Michael L., and John B. Stall, The Illinois Urban Drainage Area Simulator, ILLUDAS.

4. O'Brien & Gere Engineers, Inc., Hydro Brake Demonstration Project - Santee Drainage Area Progress Report, June, 1981.

5. Gore & Storrie Limited, Evaluation of the "Hydro Brake" Flow Regulator, Report SCAT-7 for Canada Mortgage and Housing Corporation.

6. Paul Theil Associates Limited, Borough of York Sewer Surcharging and Flooding Relief Study by Implementing Hydro Brake System, June, 1977.

7. O'Brien & Gere Engineers, Inc., Hydro Brake Demonstration Project - Santee Drainage Area - Rochester, New York, February, 1981.

BIBLIOGRAPHY

Contractors Data Report - Nationwide Tabulated Bid Results - Ohio Listings.

Dames & Moore Water Pollution Control Engineering Services, Construction Costs for Municipal Wastewater Conveyance Systems: 1973-1977, EPA Technical Report 430/9-77-014, May, 1978.

Field, Richard, Anthony N. Tafuri and Hugh E. Masters, Urban Runoff Pollution Control Technology Overview, Storm and Combined Sewer Section - Municipal Environmental Research Laboratory, EPA - 600/2-77-047, March, 1977.

Freeman, Peter A., Peter A. Freeman Assoc., Inc., Evaluation of Fluidic Combined Sewer Regulators Under Municipal Service Conditions, EPA Demonstration Grant No. 11022 FWR, EPA - 600/2-77-071, August, 1977.

Mallory, C.W., The Beneficial Use of Stormwater, EOA - R2-73-139, January, 1973.

Sarikelle, Somsek, Overview of Hydrograph and Routing Techniques and Introduction to Modeling, in Proceedings of Urban Runoff Seminar, University of Akron, December 10, 1976.

Sullivan, Richard H., et. al., American Public Works Association, The Helical Bend Combined Sewer Overflow Regulator, EPA - 600/2-75-062, December, 1975.

APPENDIX A

FORMULAE, HEAD VS. VOLUME TABLES

1. Ungula of a cylinder - calculation of volume increments for head vs. volume relationships.

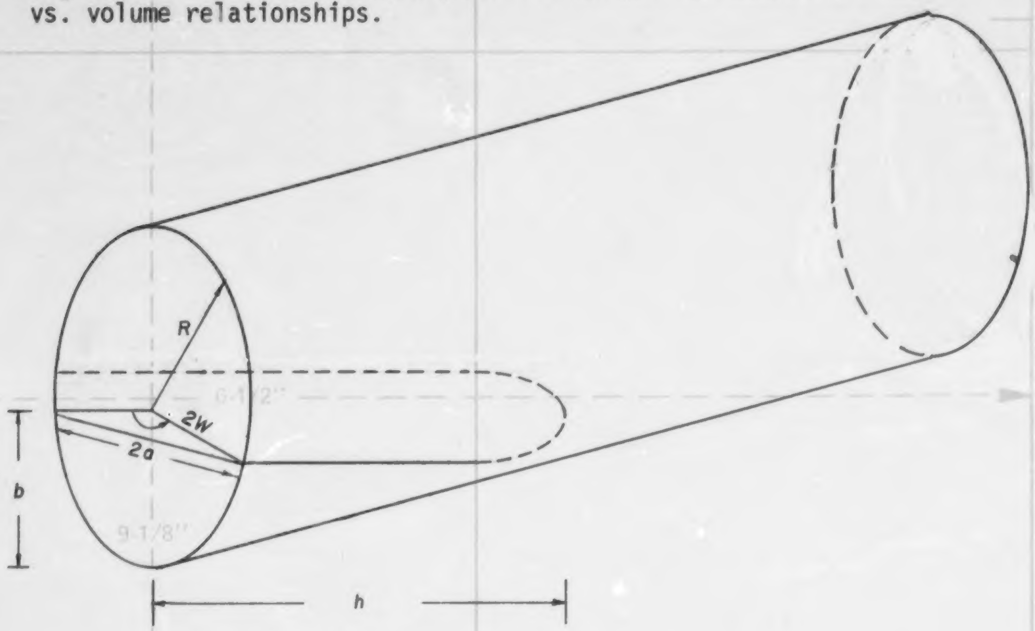

Figure A-1. Ungula of a cylinder

$$\text{Volume} = \frac{h}{3b}\left[a(3R^2-a^2) + 3R^2\,(b-R)\,W\right]$$

Where b = depth of water measured at downstream end of storage tank
r = radius of storage tank
2a = width of water surface
h = length of volume section (varies with b and slope of tank)
2w = central angle of chord defined by b and r

2. Construction of Sub-Hydrographs (design storm evaluation)

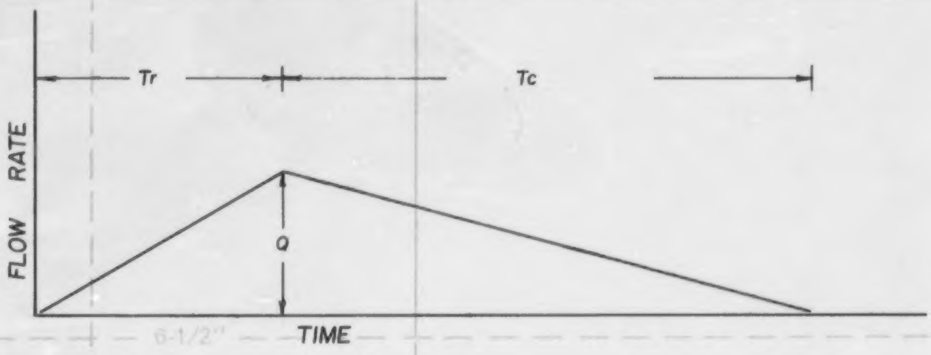

Figure A-2. Design Storm Sub-Hydrograph

$Q = CIA\,(2tr)/(tr + tc),\ tr \ll tc$

Where Q = Peak flow rate in cfs
C = Runoff coefficient
I = Rainfall increment intensity in in/hr
A = Drainage area in acres
tr = Duration of rainfall increment
tc = Time of concentration of drainage area

3. Hydrograph Routing - Design storm discharge simulation

For convenience in hydrograph routing, it is assumed that the average of flows at the start and end of a small time increment is equivalent to the average flow during this increment.

Therefore, the storage continuity equation:

$$I - 0 = \frac{ds}{dt}$$

May be rewritten as:

$$\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} = \frac{S_2 - S_1}{dt}$$

Where O_1 = discharge at time t_1
O_2 = discharge at time t_2
I_1 = inflow at time t_1
I_2 = inflow at time t_2
S_2 = storage at time t_2
S_1 = storage at time t_1
$dt = t2 - t_1$

Rearranging yields:

$$I_1 + I_2 + (2S_1/dt - O_1) = 2S_2/dt + O_2$$

All terms on the left side of the equation are known, so the value of the right side may be calculated. From known relationships for H vs. S and H vs. Q, a graph of 2S/dt + O vs. O may be constructed. To solve the routing problem, successive inflow values are input to determine corresponding discharge values (O_2). These discharge values are then used to repeat the calculation until all influent flows have been input through the relationship to construct the corresponding discharge hydrograph.

4. Head vs. Volume Relationships

Table A-1 presents cumulative volumes in cubic feet for one inch incremental changes in water depth in each Hydro Brake retention structure. Depth is measured at the downstream end of each structure and includes volumes for catch basin leads, manholes and storm sewer segments where applicable.

TABLE A-1

Depth*	Cumulative Volume in Cubic Feet		
(Inches)	W. 170 St.	W. 177 St.	Puritas Ave.
1	0.5	1	1
2	2	6	5
3	7	15	15
4	13	30	30
5	23	51	52
6	37	80	83
7	54	116	121
8	75	161	169
9	100	214	226
10	129	275	293
11	163	346	368
12	200	426	451
13	242	516	540
14	287	615	633
15	337	723	730
16	391	842	830
17	451	970	932
18	516	1109	1037
19	585	1257	1143
20	610	1414	1250
21	675	1578	1359
22	743	1746	1469
22	811	1914	1579
24	880	2084	1690

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Depth (Inches)	Cumulative Volume in Cubic Feet		
	W. 170 St.	W. 177 St.	Puritas Ave.
25	951	2260	1801
26	1021	2439	1914
27	1091	2622	2026
28	1161	2807	2139
29	1230	2993	2252
30	1298	3180	2365
31	1365	3369	2478
32	1429	3557	2590
33	1492	3746	2702
34	1553	3923	2814
35	1611	4123	2926
36	1667	4311	3037
37	1721	4498	3095
38	1773	4684	3257
39	1824	4868	3366
40	1874	5053	3474
41	1923	5236	3581
42	1971	5418	3688
43	2015	5598	3794
44	2067	5777	3899
45	2108	5955	4002
46	2146	6131	4105
47	2181	6305	4207
48	2214	6477	4307
49	2240	6647	4406
50	2261	6815	4503
51	2279	6980	4600
52	2293	7143	4694
53	2304	7303	4787
54	2311	7460	4878
55	2316	7614	4968
56	2318	7765	5055

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9-1/8"

Depth	Cumulative Volume in Cubic Feet		
(Inches)	W. 170 St.	W. 177 St.	Puritas Ave.
57	2319	7912	5141
58		8056	5224
59		8195	5305
60		8330	5384
61		8461	5460
62		8586	5533
63		8706	5603
64		8819	5671
65		8925	5734
66		9023	5794
67		9114	5850
68		9196	5900
69		9271	5945
70		9338	5983
71		9398	6015
72		9452	6042
73		9498	6062
74		9539	6078
75		9573	6089
76		9601	6096
77		9624	6100
78		9642	6101
79		9655	
80		9665	
81		9670	
82		9673	
83		9675	

* "b" in Figure A-1

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APPENDIX B

HOMEOWNER SURVEY FORMS

PURITAS AREA QUESTIONNAIRE

(PRE-CONSTRUCTION)

ADDRESS ____

1. Have you experienced basement flooding?

   If so, when and how often?

2. What is the deepest that the water has ever appeared in your basement:

3. Does your street experience street flooding during a storm or during a rainy season?

   If so, when and how often?

   If the street does flood, at what location is the water present?

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PURITAS AREA QUESTIONNAIRE

(POST-CONSTRUCTION)

ADDRESS: ______________________________

1. Have you experienced basement flooding in recent months? ________
   If so, when, how deep? ______________________________
   ____
   ____

2. Does your street experience street flooding during a storm or during a rainy season? ________
   If so, where? ______________________________
   ____

3. Do you have any sewage odor problems? ________
   Explain when. ______________________________
   ____

4. Are these odors more noticeable during rain storms? ________

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APPENDIX C

STORM WATER QUALITY SAMPLING RESULTS

SAMPLING LOC.: W177 DATE OF SAMPLE: July 13, 1981

PARAMETERS	Time of Sample Taken (min.) 2.5	5.0	10	15	30	Composite
BOD mg/l	34	48	52	59	51	--
Suspended Solids mg/l	98	80	79	88	80	--
Volatile Suspended Solids mg/l	15	13	14	10	10	--
Cadmium mg/l	--	--	--	--	--	0.01
Total Chromium mg/l	--	--	--	--	--	LT 0.01
Chloride mg/l	--	--	--	--	--	6.3
Copper mg/l	--	--	--	--	--	0.02
Lead mg/l	--	--	--	--	--	0.10
Sulfate mg/l	--	--	--	--	--	8.5
Zinc mg/l	--	--	--	--	--	0.16
Total Organic Carbon mg/l	--	--	--	--	--	12
COD mg/l	--	--	--	--	--	39
Settleability ml/l	--	--	--	--	--	LT 0.18

LT = Less Than

SAMPLING LOC.: W170

DATE OF SAMPLE: July 21, 1981

PARAMETERS	Time of Sample Taken (min.) 2.5
BOD mg/l	51
Suspended Solids mg/l	91
Volatile Suspended Solids mg/l	32
Cadmium mg/l	0.01
Total Chromium mg/l	0.01
Chloride mg/l	13
Copper mg/l	0.03
Lead mg/l	LT 0.01
Sulfate mg/l	8.6
Zinc mg/l	0.15
Total Organic Carbon mg/l	7
COD mg/l	100
Settleability ml/l	LT 0.32

LT - Less Than

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SAMPLING LOC.: W177 DATE OF SAMPLE: July 28, 1981

PARAMETERS	Time of Sample Taken (min.) 90	120	150	180	210	Composite
BOD mg/l	10	29	17	19	21	--
Suspended Solids mg/l	61	56	40	58	35	--
Volatile Suspended Solids mg/l	13	10	7	16	10	--
Cadmium mg/l	--	--	--	--	--	0.01
Chromium mg/l	--	--	--	--	--	0.01
Chloride mg/l	--	--	--	--	--	9
Copper mg/l	--	--	--	--	--	0.03
Lead mg/l	--	--	--	--	--	0.01
Sulfate mg/l	--	--	--	--	--	27
Zinc mg/l	--	--	--	--	--	0.18
Total Organic Carbon mg/l	--	--	--	--	--	26
COD mg/l	--	--	--	--	--	40
Settleability ml/l	--	--	--	--	--	LT 0.18

LT - Less Than

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SAMPLING LOC.: W177 DATE OF SAMPLE: July 28, 1981

	Time of Sample Taken (min.)					
PARAMETERS	2.5	5.0	10	15	30	60
BOD mg/l	27	22	17	18	15	13
Suspended Solids mg/l	74	82	69	56	110	72
Volatile Suspended Solids mg/l	16	15	14	15	16	12

SAMPLING LOC.: W170

DATE OF SAMPLE: August 8, 1981

PARAMETERS	Time of Sample Taken (min.) 2.5	5.0	10	15	Composite
BOD mg/l	21	28	12	13	--
Suspended Solids mg/l	210	180	100	110	--
Volatile Suspended Solids mg/l	65	60	30	30	--
Cadmium mg/l	--	--	--	--	0.01
Total Chromium mg/l	--	--	--	--	0.01
Chloride mg/l	--	--	--	--	11
Copper mg/l	--	--	--	--	0.05
Lead mg/l	--	--	--	--	0.12
Sulfate mg/l	--	--	--	--	12
Zinc mg/l	--	--	--	--	0.26
Total Organic Carbon mg/l	--	--	--	--	36
COD mg/l	--	--	--	--	110
Settleability ml/l	--	--	--	--	1.2

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SAMPLING LOC.: W170 **DATF OF SAMPLE:** August 17, 1981

PARAMETERS	Time of Sample Taken (min.)			
	30	60	90	120
BOD mg/l	19	19	16	19
Suspended Solids mg/l	58	83	70	61
Volatile Suspended Soilds mg/l	21	18	24	20

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SAMPLING LOC.: W170

DATE OF SAMPLE: August 17, 1981

	Time of Sample Taken (min.)				
PARAMETERS	**2.5**	**5.0**	**10**	**15**	**Composite**
BOD mg/l	23	22	21	20	--
Suspended Solids mg/l	90	62	50	48	--
Volatile Suspended Solids mg/l	31	24	20	20	--
Cadmium mg/l	--	--	--	--	0.02
Total Chromium mg/l	--	--	--	--	LT 0.01
Chloride mg/l	--	--	--	--	28
Copper mg/l	--	--	--	--	0.33
Lead mg/l	--	--	--	--	0.07
Sulfate mg/l	--	--	--	--	21
Zinc mg/l	--	--	--	--	0.22
Total Organic Carbon mg/l	--	--	--	--	50
COD mg/l	--	--	--	--	53
Settleability ml/l	--	--	--	--	0.98

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APPENDIX D

STORAGE TANK PHOTOGRAPHS AND SEDIMENT RECORDS

Photographs were taken in November, 1981, after the Hydro Brake control/retention structures had been in operation approximately 18 months. Each series of photographs starts at the downstream end of the structures and proceeds up the tanks at approximately 25 foot (7.6 M) intervals. Each photograph includes descriptive comments using the following format:

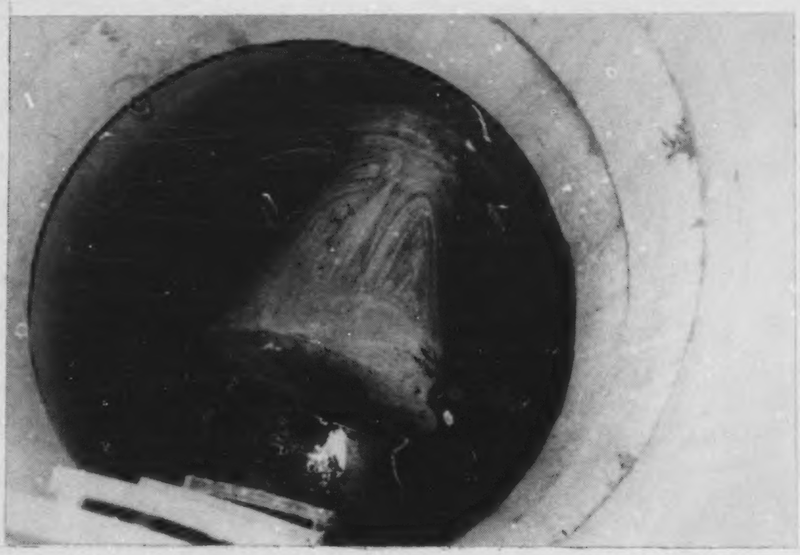
Picture No.

(a) Location or approximate distance from downstream bulkhead, etc.
(b) Sediment measurements, comments - September, 1980
(c) Sediment measurements, comments - November, 1981

Note that construction timbers were still in place in the Puritas and W. 177th Street structures.

Puritas Avenue

#1. (a) View of 16" (41 cm) Hydro Brake in place
(b) --
(c) --



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#2. (a) West Bulkhead
(b) 1" (2.5 cm) standing water
(c) 1" (2.5 cm) standing water

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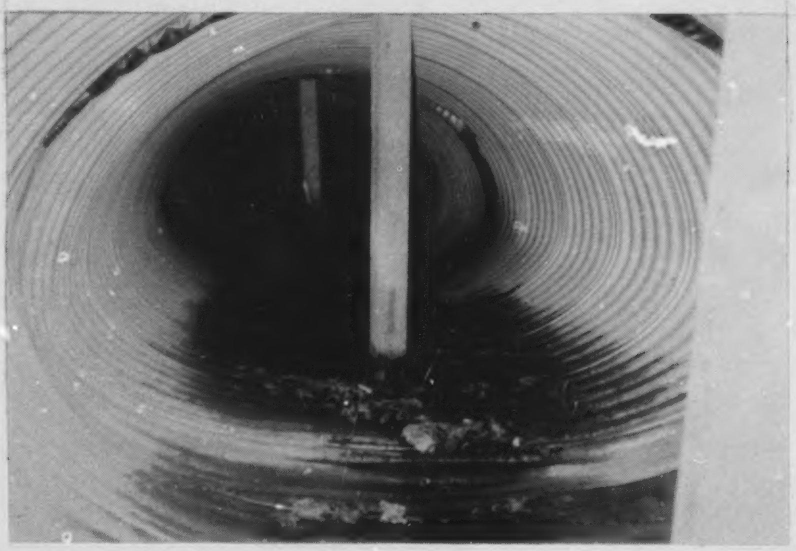
#3. (a) 25 feet (7.6 M)
(b) 1" (2.5 cm) standing Water
(c) 1" (2.5 cm) standing Water



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#4. (a) 50 feet (15 M)
(b) 1" (2.5 cm) standing water
(c) 1" (2.5 cm) standing water

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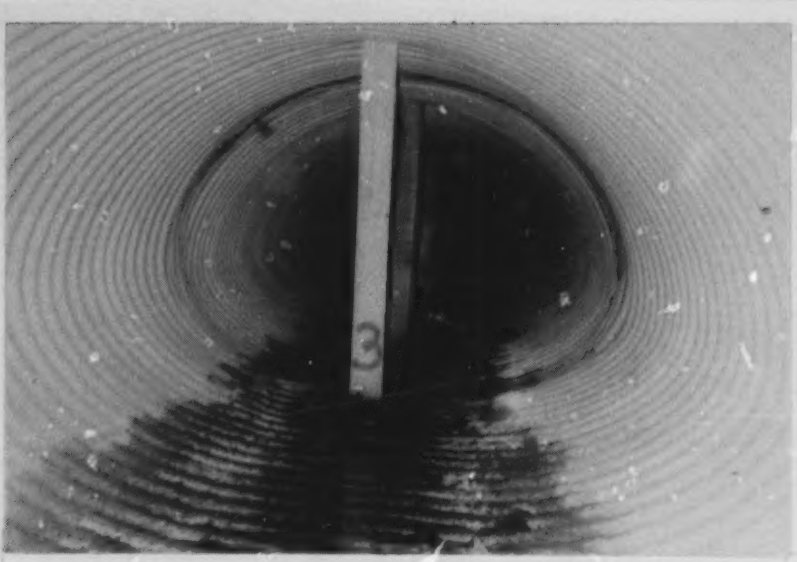
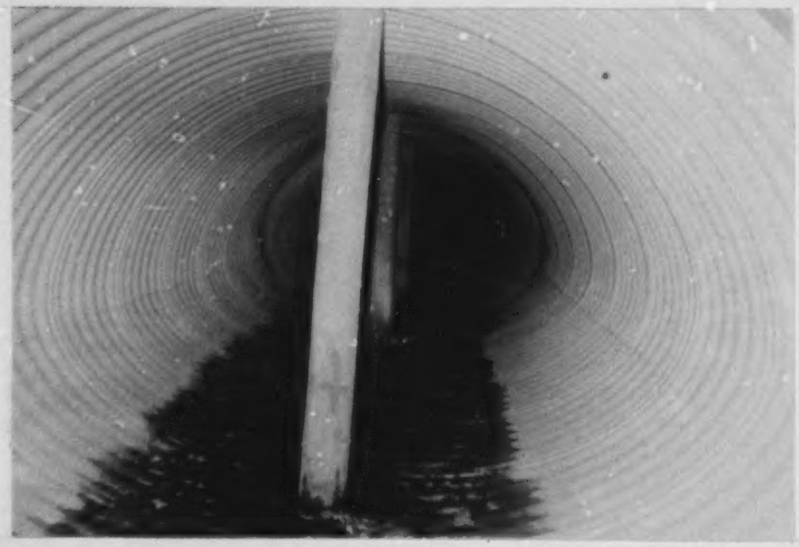


#5. (a) 75 feet (23 M)
(b) 1" (2.5 cm) standing water
(c) 1" (2.5 cm) standing water



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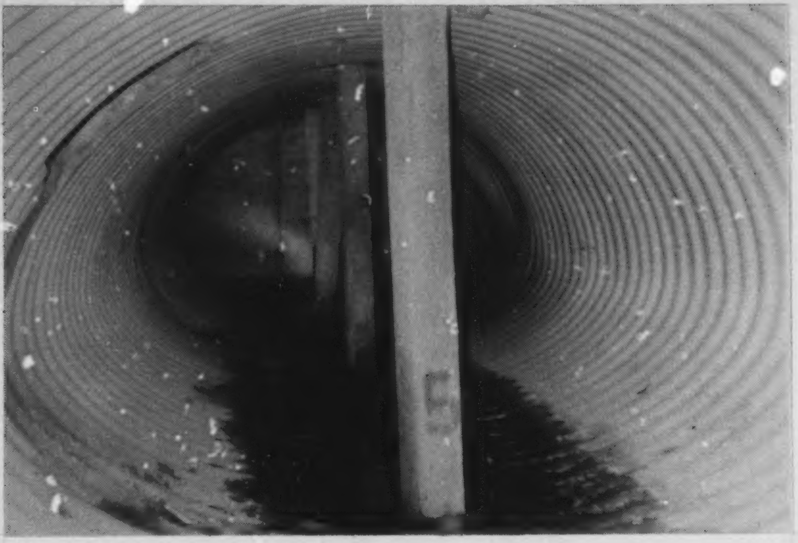
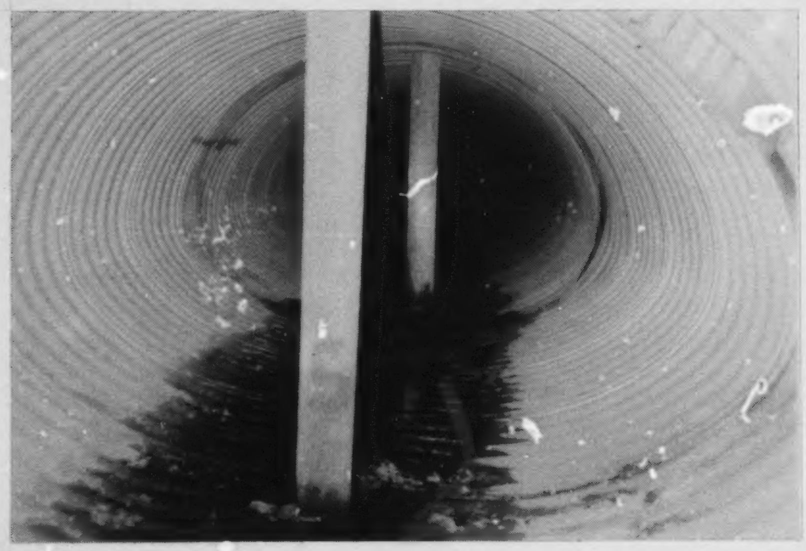
#6. (a) 100 feet (30.5 M)
(b) 1" (2.5 cm) standing water
(c) 1" (2.5 cm) standing water



#7. (a) 125 feet (38.1 M) - View of East Bulkhead
(b) 1" (2.5 cm) standing water
(c) Dry



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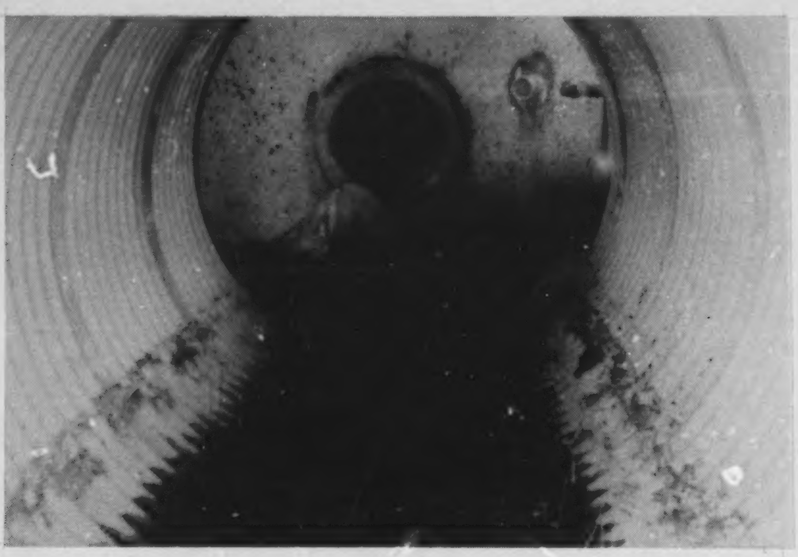
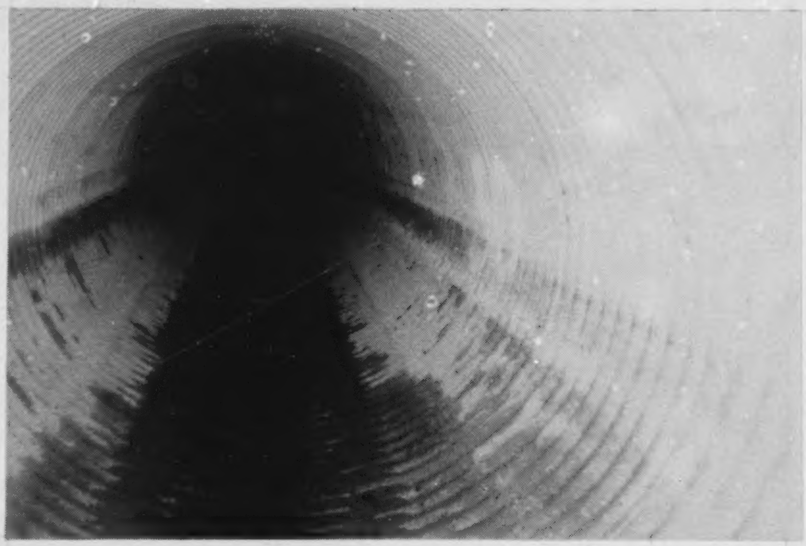
W. 170th Street

#1. (a) Downstream Manhole with 9" (23 cm) Hydro Brake in place
(b) 3" (7.6 cm) sediment
(c) 1" (2.5 cm) sediment



#2. (a) 25 feet (7.6 cm)
(b) 3" (7.6 cm) sediment
(c) 1" (2.5 cm) sediment



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#3. (a) 50 feet (15 M)
(b) 3" (7.6 cm) sediment
(c) 1" (2.5 cm) sediment

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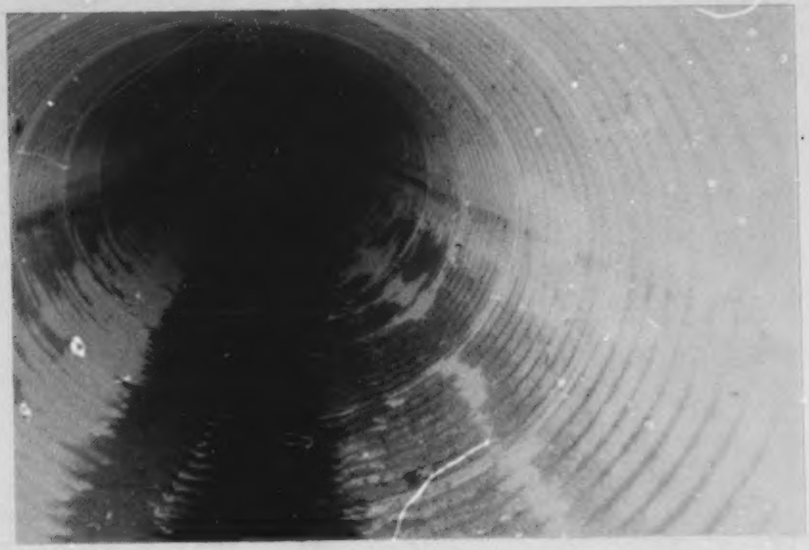
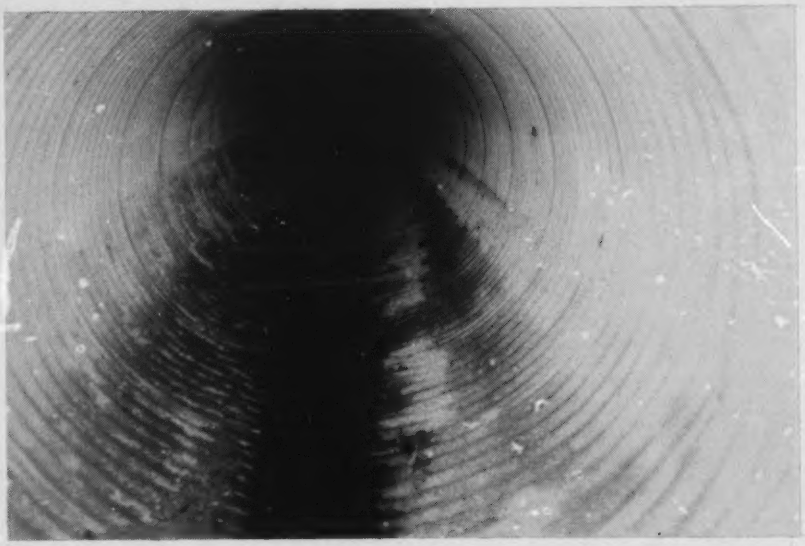


#4. (a) 75 feet (23 M)
(b) Dry
(c) 1" (2.5 cm) sediment



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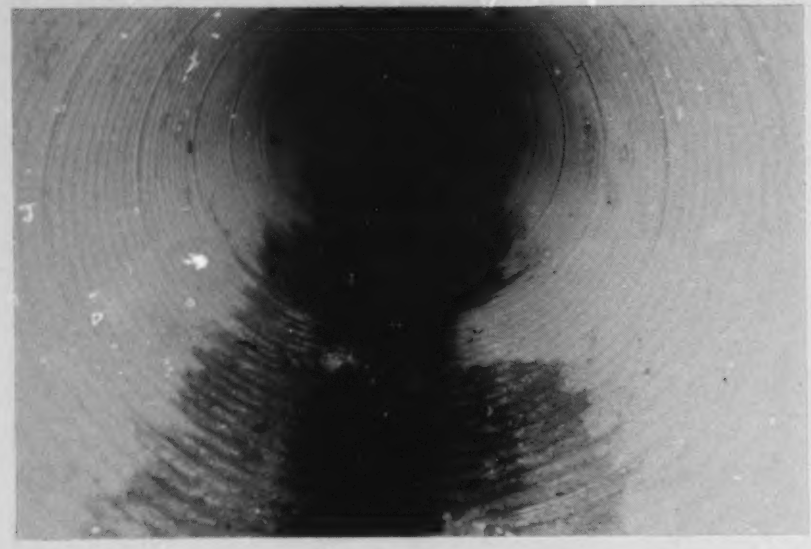
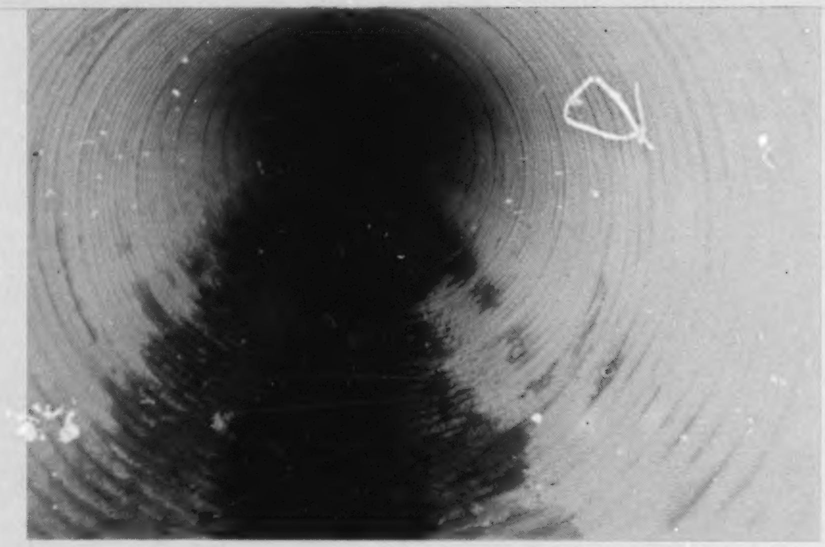
#5. (a) 100 feet (30.5 M)
(b) 1" (2.5 cm) standing water
(c) 1" (2.5 cm) sediment



#6. (a) 125 feet (38.1 M)
(b) 2" (5.1 cm) standing water
(c) 3" (7.6 cm) sediment & water



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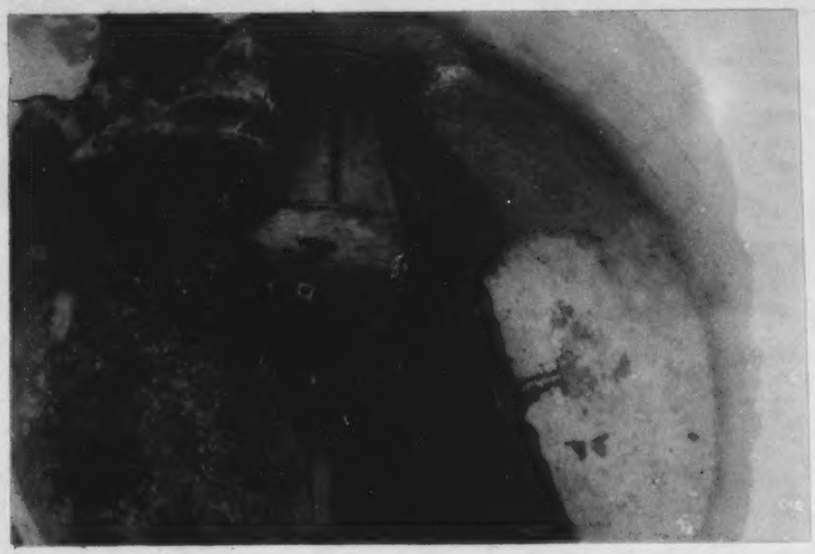
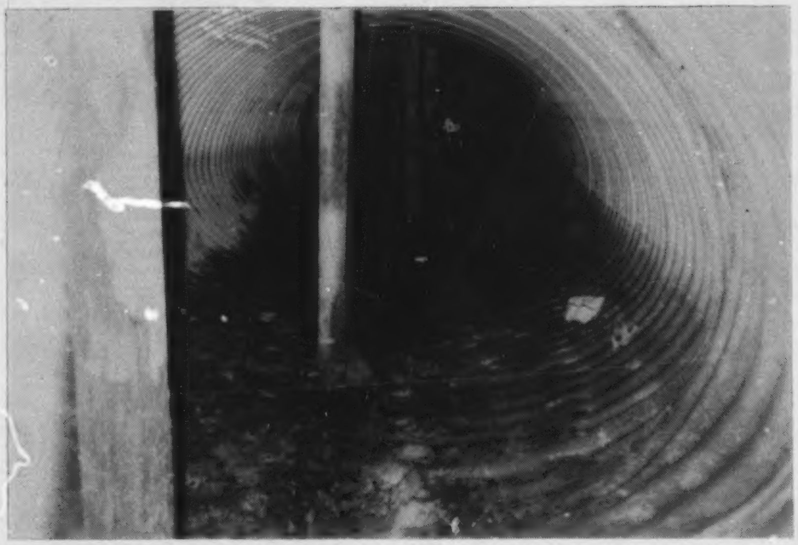
W. 177th Street

#1. (a) 7" (18 cm) Hydro Brake in place
(b) --
(c) --



#2. (a) 25 feet (7.6 M) - East tank
(b) 1" (2.5 cm) standing water
(c) 3" (7.6 cm) sediment



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#3. (a) 50 feet (15 M)
(b) 1" (2.5 cm) standing water
(c) 2" (5.1 cm) standing water

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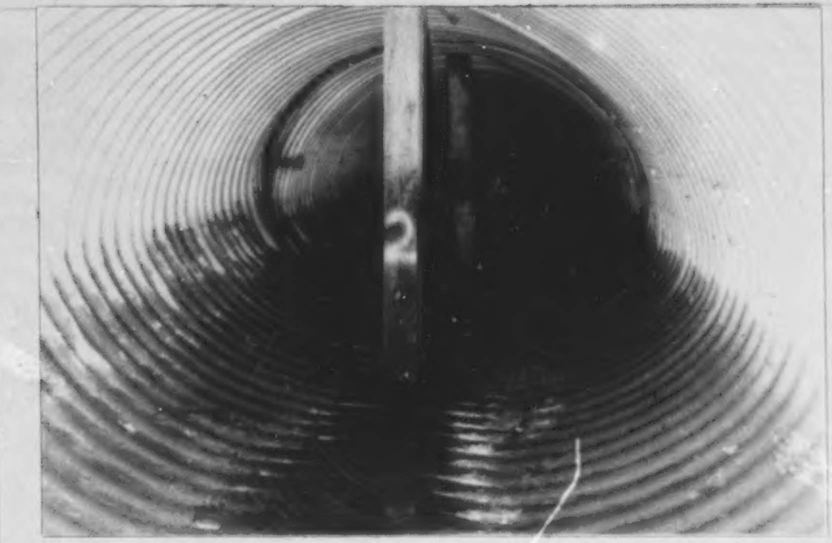
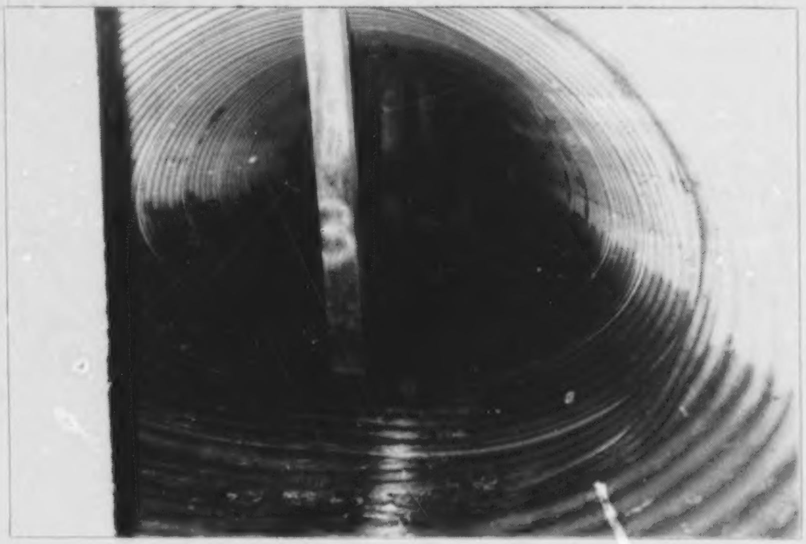


#4. (a) 75 feet (23 M)
(b) 2" (5.1 cm) standing water
(c) 1" (2.5 cm) sediment



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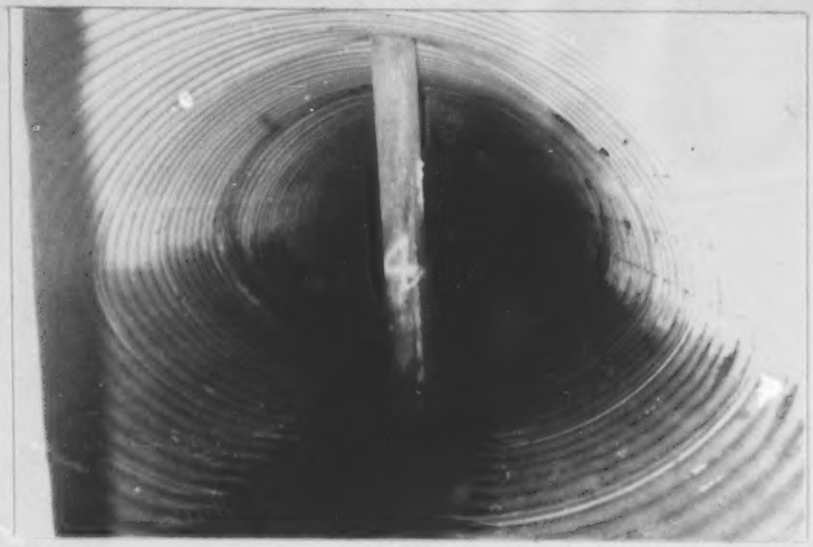
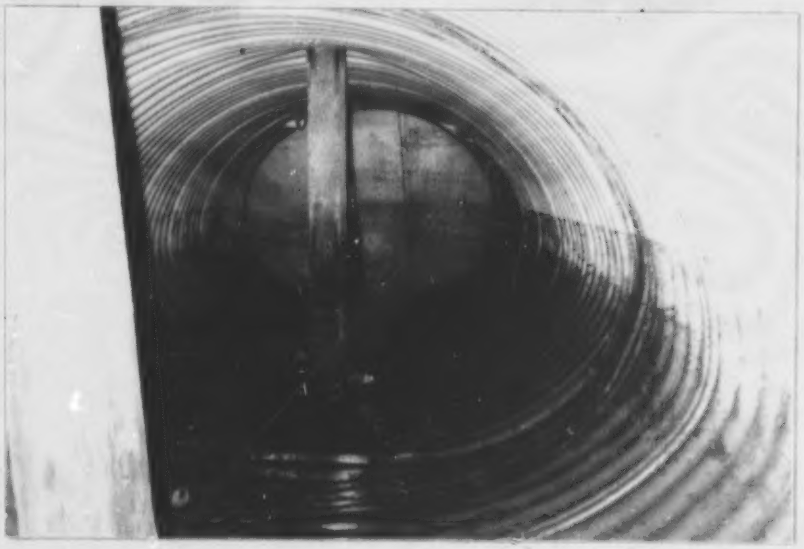
#5. (a) 100 feet (30.5 M)
(b) 1" (2.5 cm) standing water
(c) 1" (2.5 cm) sediment



#6. (a) 125 feet (38.1 M) view of South Bulkhead (East tank)
(b) 2" (5.1 cm) standing water
(c) 2" (5.1 cm) standing water



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#7. (a) North Bulkhead (West tank) - effluent pipe to Hydro Brake Manhole
(b) 2" (5.1 cm) standing water
(c) 2" (5.1 cm) standing water

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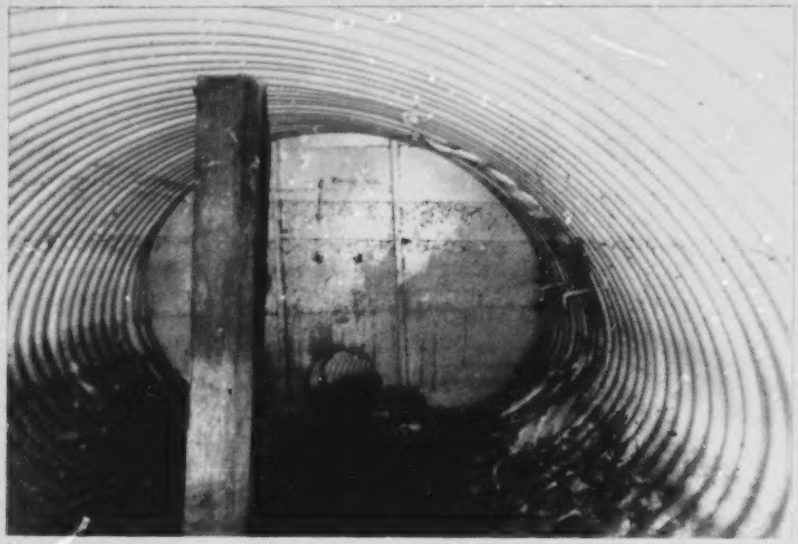
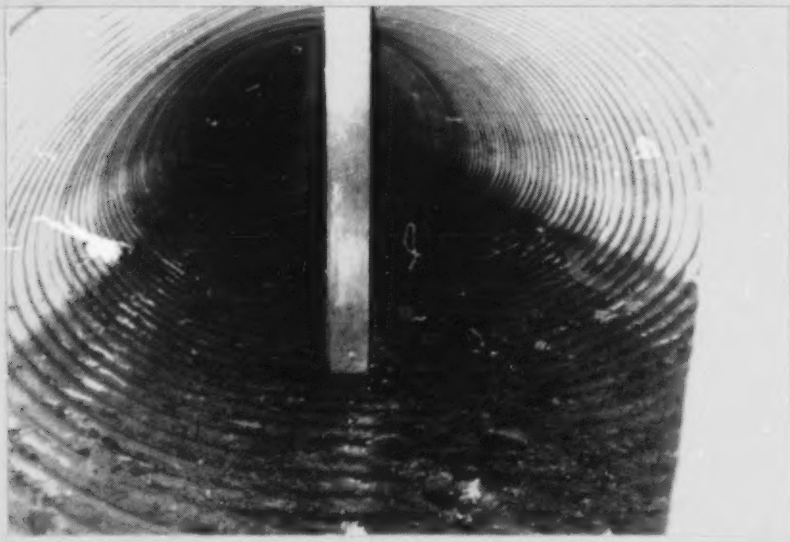


#8. (a) 25 feet (7.6 M)
(b) 1" (2.5 cm) sediment
(c) 2" (5.1 cm) sediment and water



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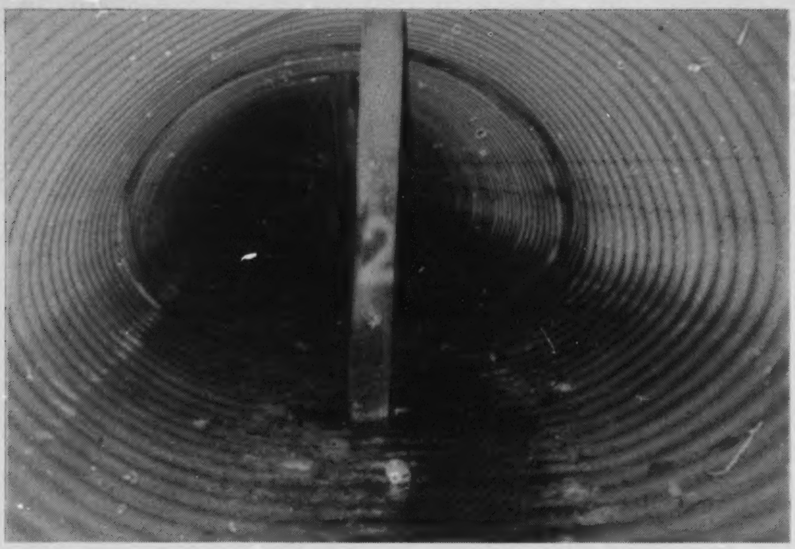
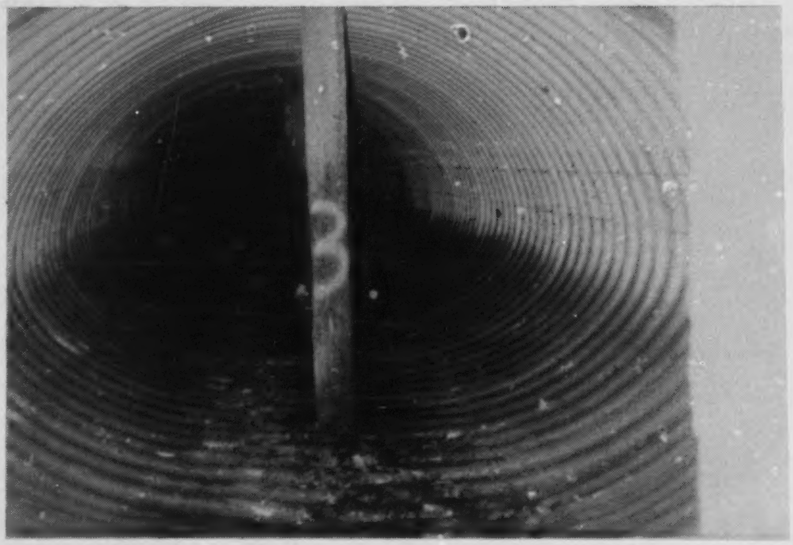
#9. (a) 50 feet (15 M)
(b) 1" (2.5 cm) standing water
(c) 1" (2.5 cm) sediment



#10. (a) 75 feet (23 M)
(b) 1" (2.5 cm) standing water
(c) 1" (2.5 cm) standing water



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#11. (a) 100 feet (30.5 M)
(b) 1" (2.5 cm) standing water
(c) 1" (2.5 cm) standing water

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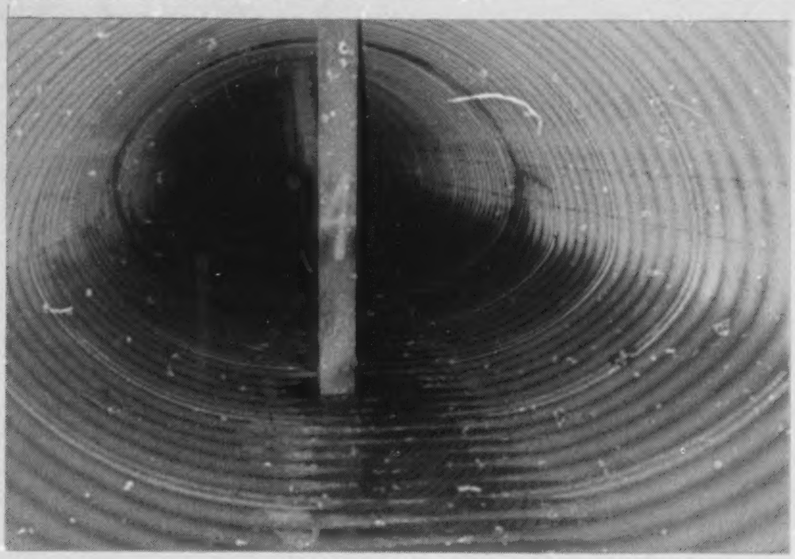
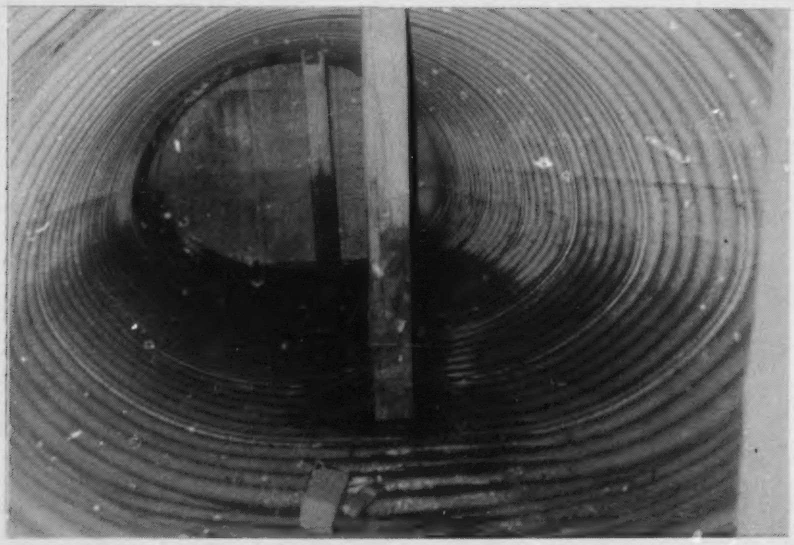


#12. (a) 125 feet (38.1 M) view of South Bulkhead (West tank)
(b) 1" (2.5 cm) standing water
(c) 1" (2.5 cm) standing water



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APPENDIX E

1/2 HOUR DURATION DESIGN STORM HYDROGRAPHS

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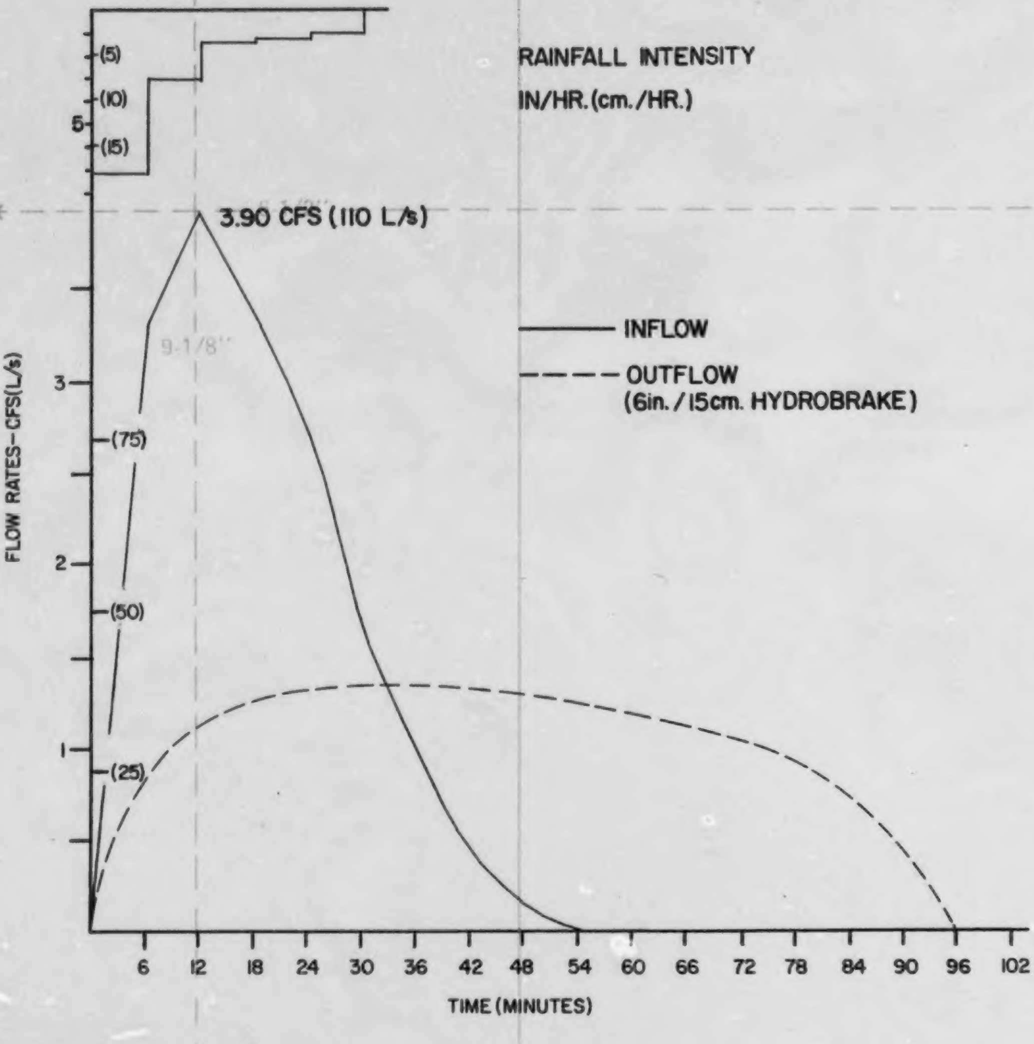

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FIGURE E-1 W. 170 ST. DESIGN STORM HYDROGRAPHS
10 YR. RETURN – 1/2 HR. DURATION (1.37in.–3.48cm.)

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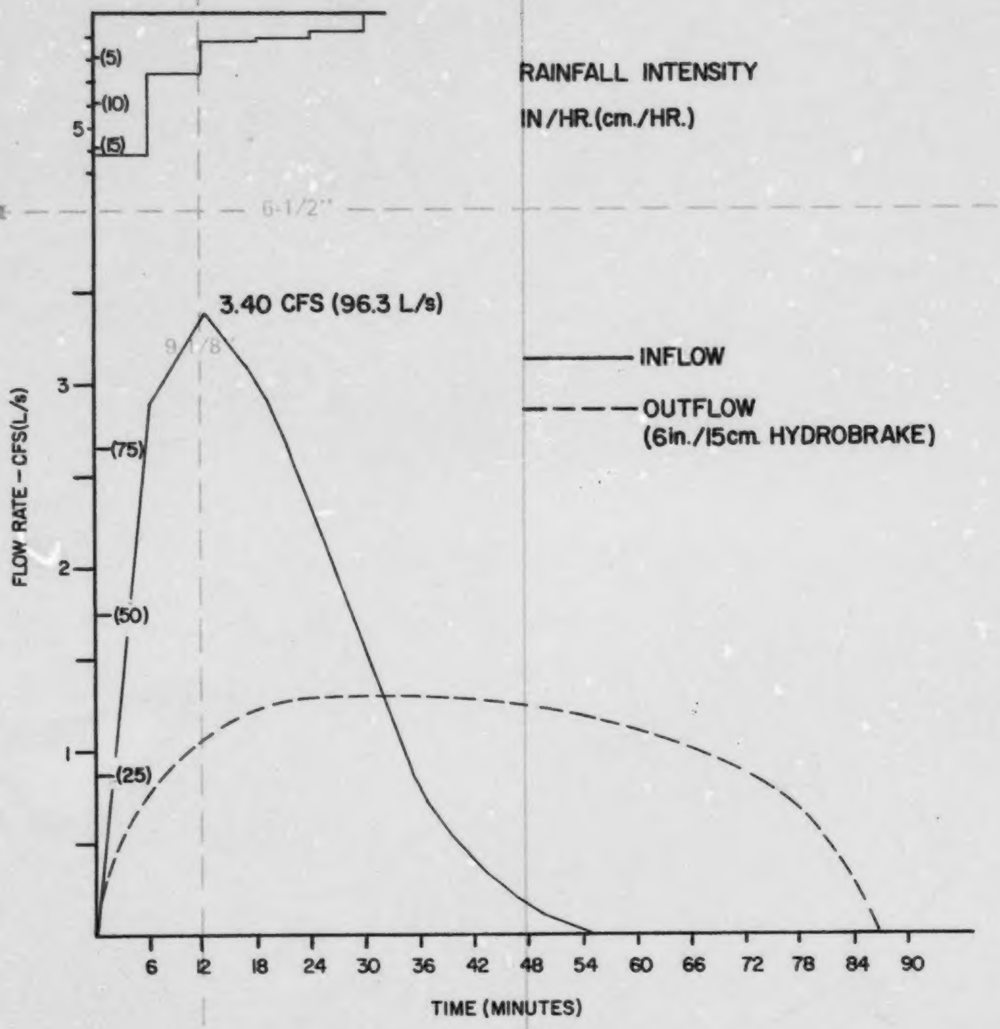

FIGURE E-2 W. 170 ST. DESIGN STORM HYDROGRAPHS
5 YR. RETURN – 1/2 HR. DURATION (1.19 in. – 3.02 cm.)

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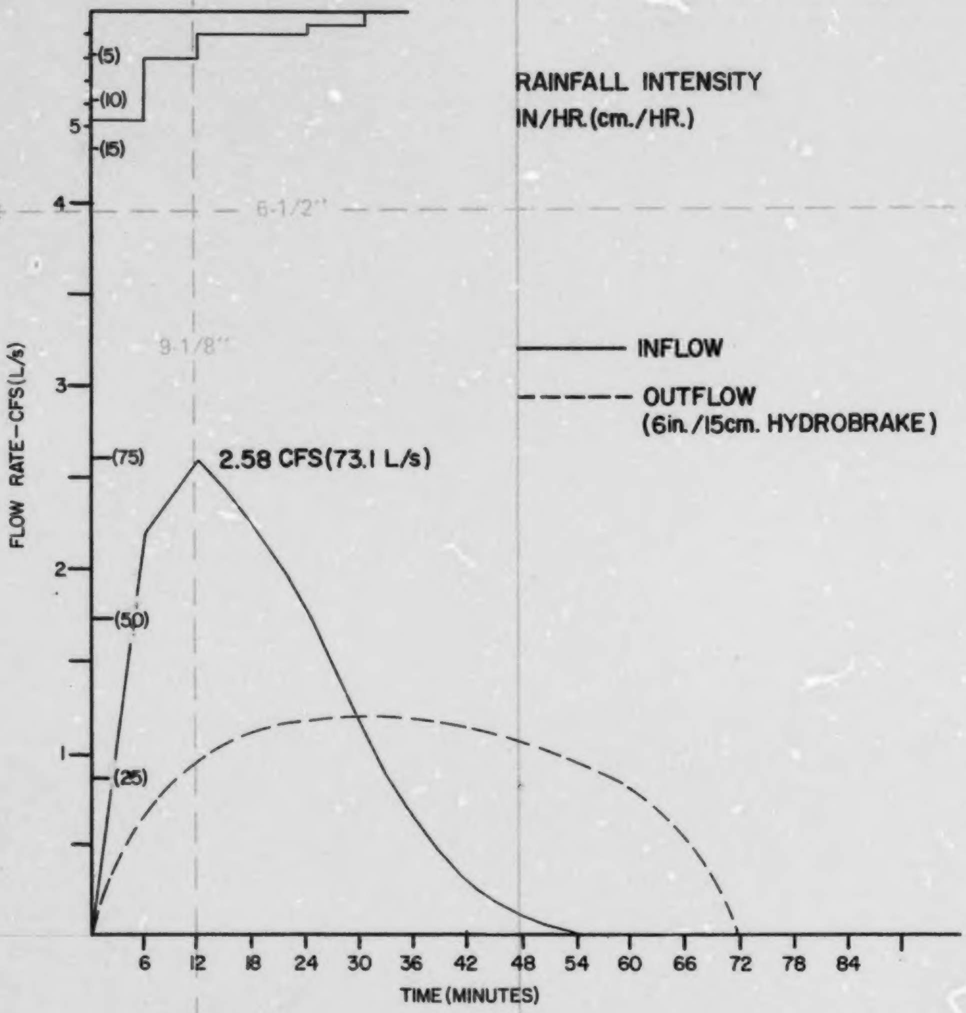

FIGURE E-3 W. 170 ST. DESIGN STORM HYDROGRAPHS
2 YR. RETURN - 1/2 HR. DURATION (.91 in. - 2.31 cm.)

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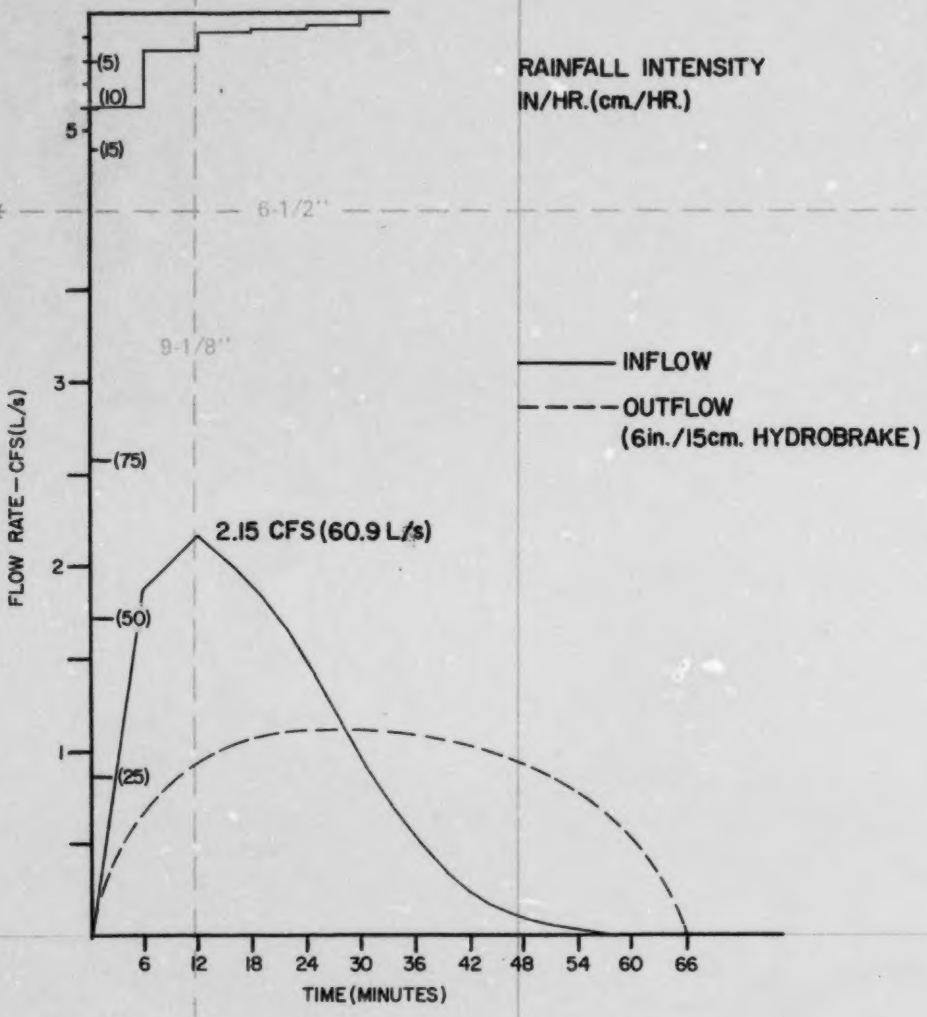

FIGURE E-4 W.170 ST. DESIGN STORM HYDROGRAPHS
1YR. RETURN-1/2 HR. DURATION (.76in.-1.93cm.)

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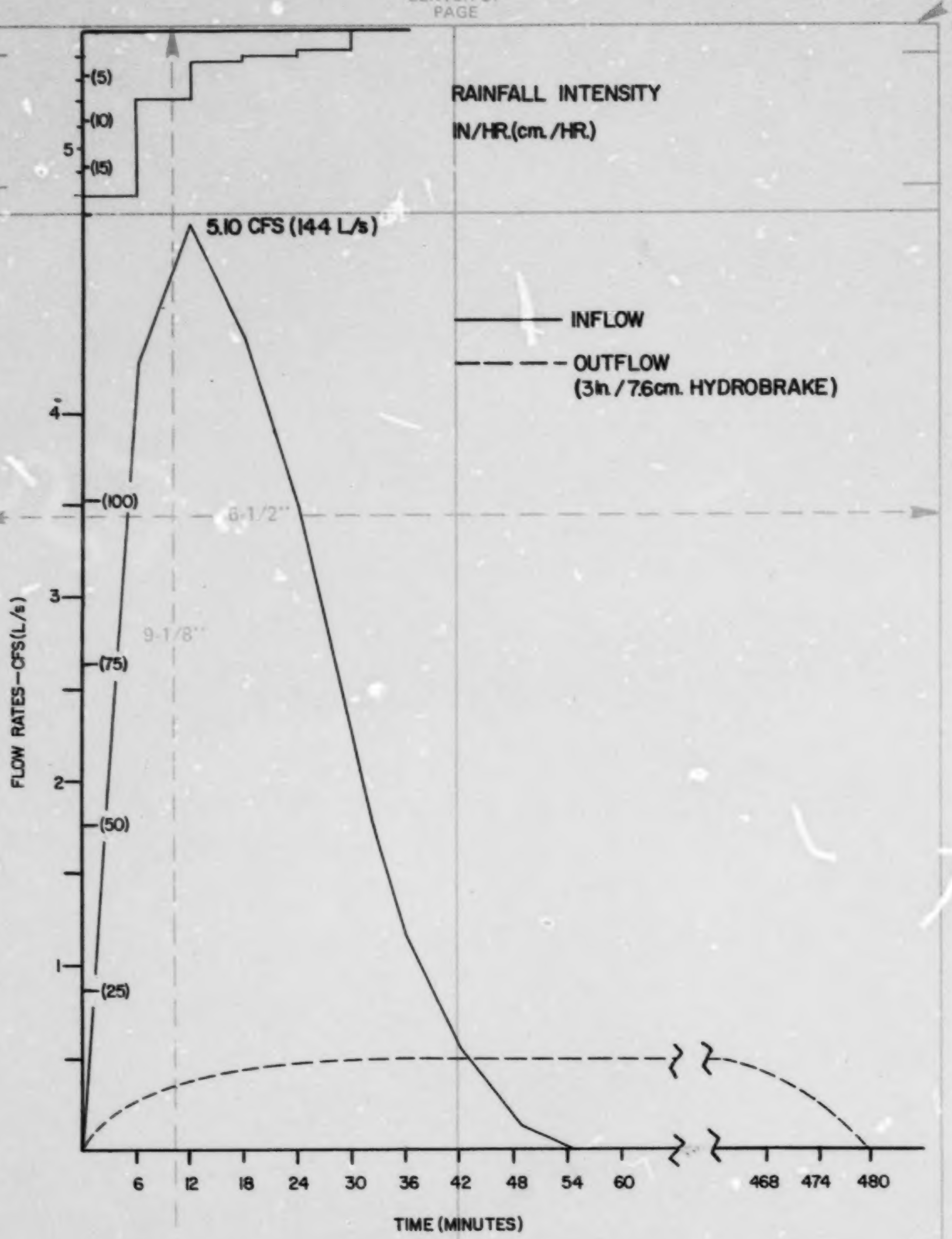

FIGURE E-5 W. 177 ST. DESIGN STORM HYDROGRAPHS
10 YR. RETURN–1/2 HR. DURATION (1.37in.–3.48cm.)

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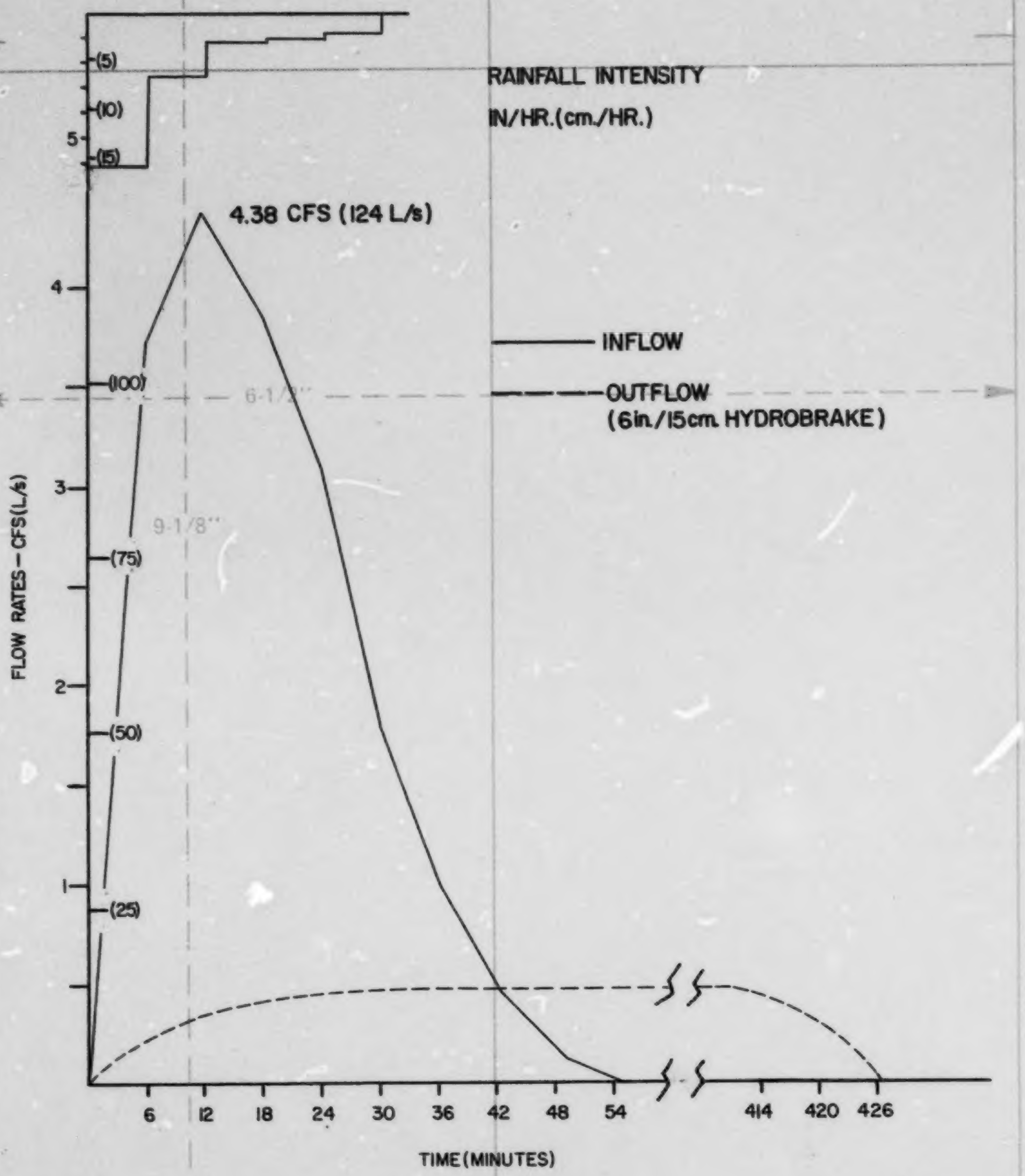

FIGURE E-6 W. 177 ST. DESIGN STORM HYDROGRAPHS
5 YR. RETURN — 1/2 HR. DURATION (1.19 in. — 3.02 cm.)

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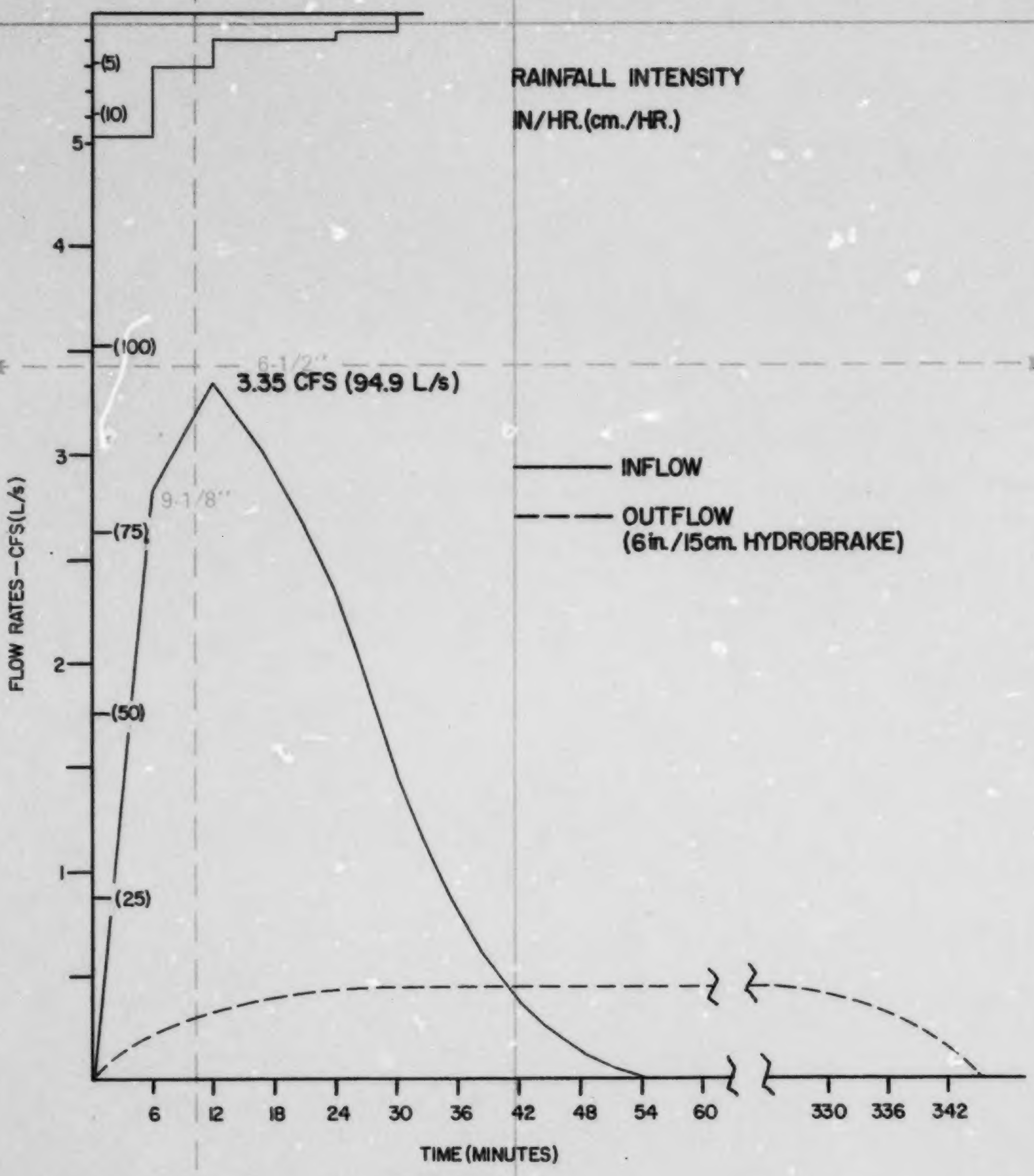

FIGURE E-7 W. 177 ST. DESIGN STORM HYDROGRAPHS
2YR. RETURN-1/2 HR. DURATION (.91in.-2.31cm.)

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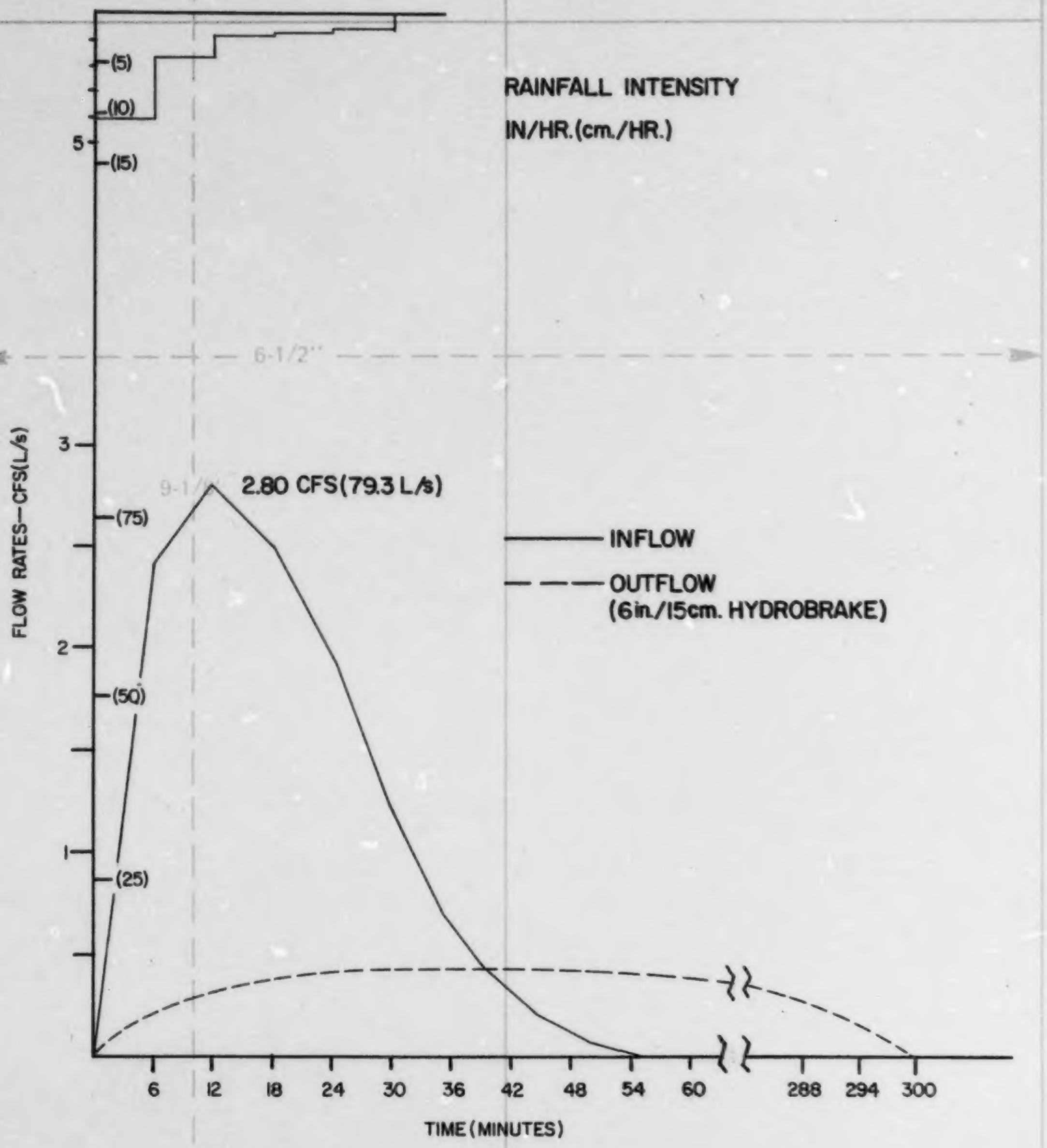

FIGURE E-8 W. 177 ST. DESIGN STORM HYDROGRAPHS
1YR. RETURN—1/2 HR. DURATION (.76in.—1.93cm.)

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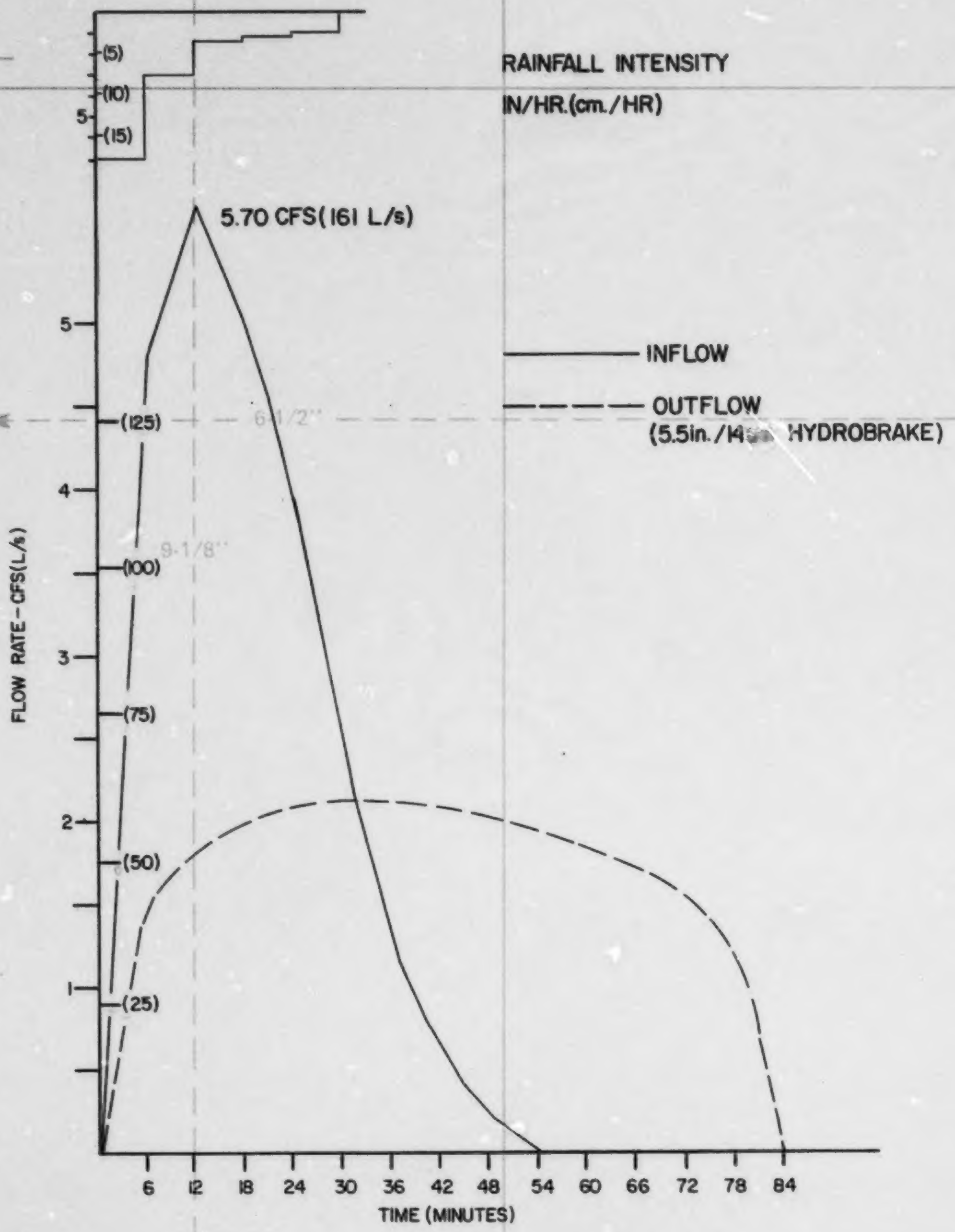

FIGURE E-9 PURITAS AVE. DESIGN STORM HYDROGRAPHS
10YR. RETURN– 1/2 HR. DURATION (1.37in.–3.48cm.)

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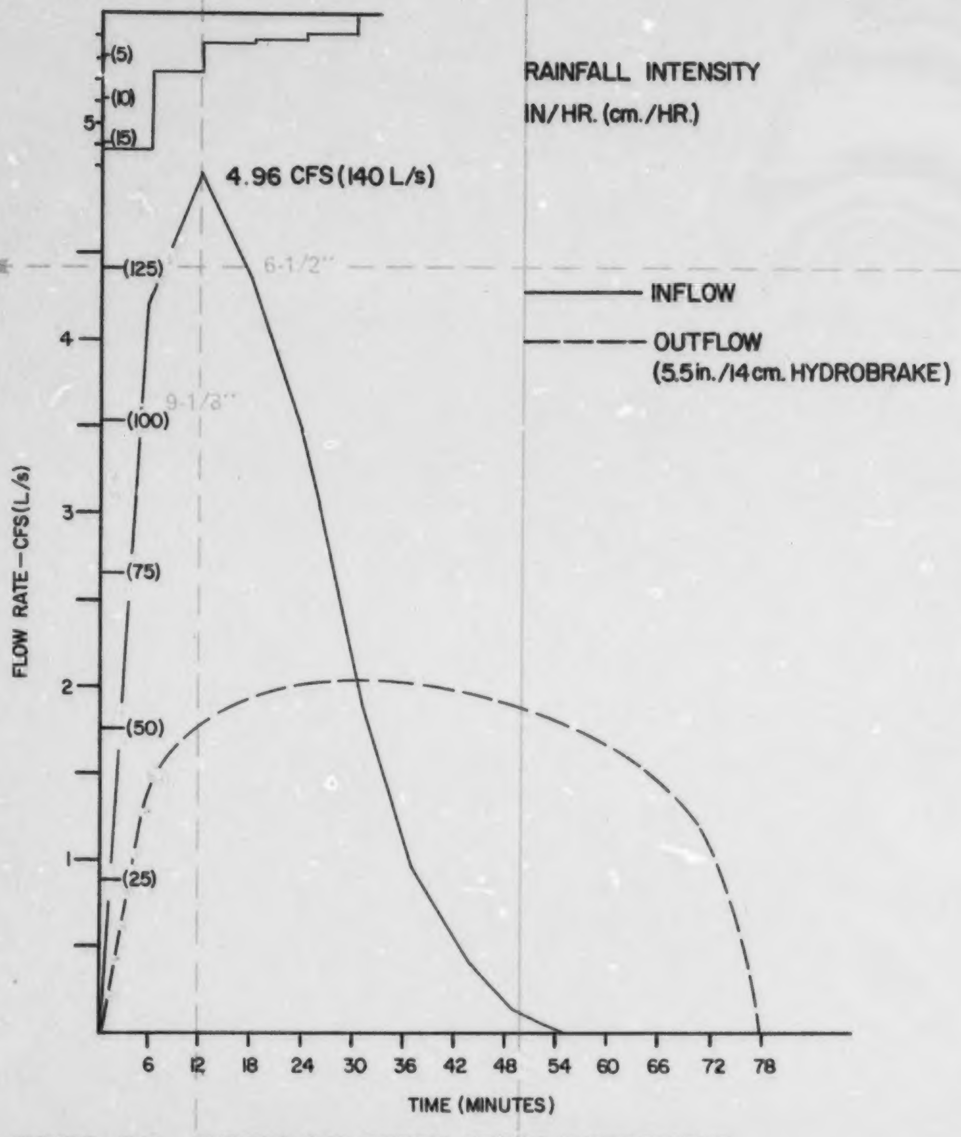

FIGURE E-10 PURITAS AVE. DESIGN STORM HYDROGRAPHS
5 YR. RETURN—1/2 HR. DURATION (1.19 in.—3.02 cm.)

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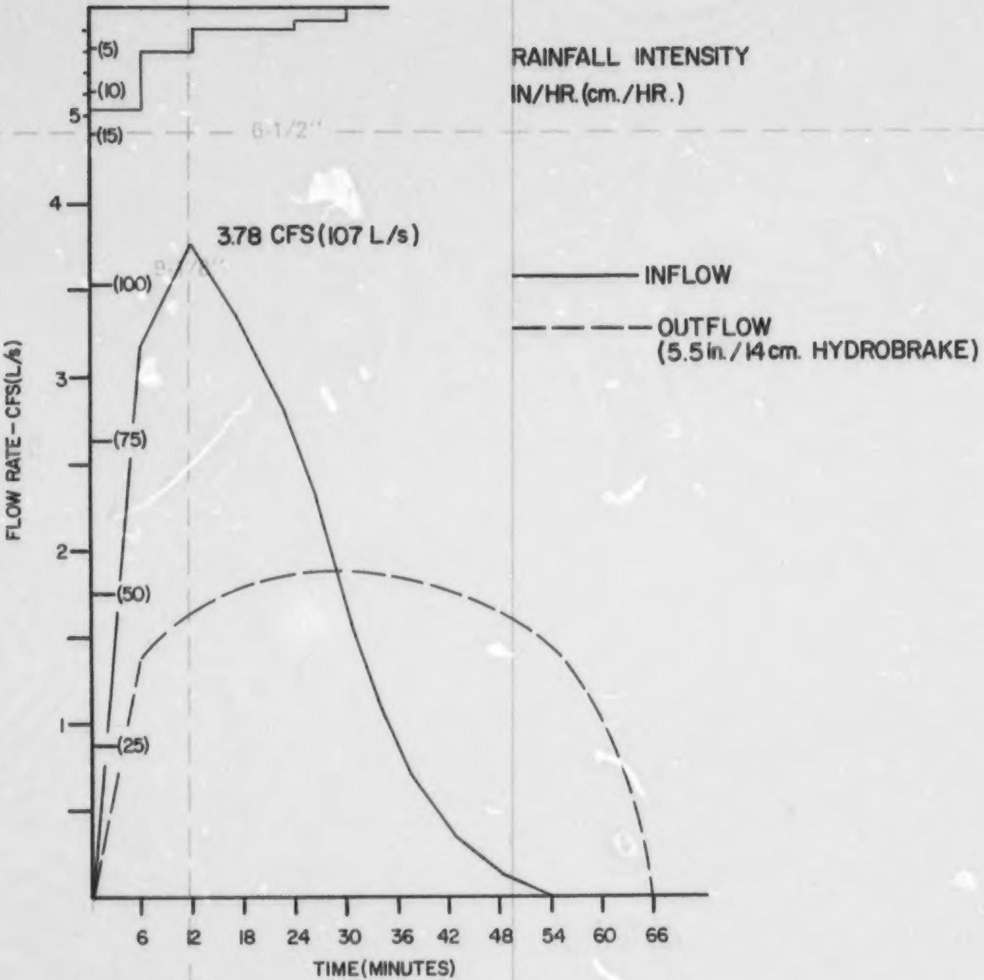

FIGURE E-11 PURITAS AVE. DESIGN STORM HYDROGRAPHS
2 YR. RETURN - 1/2 HR. DURATION (.91 in. - 2.31 cm.)

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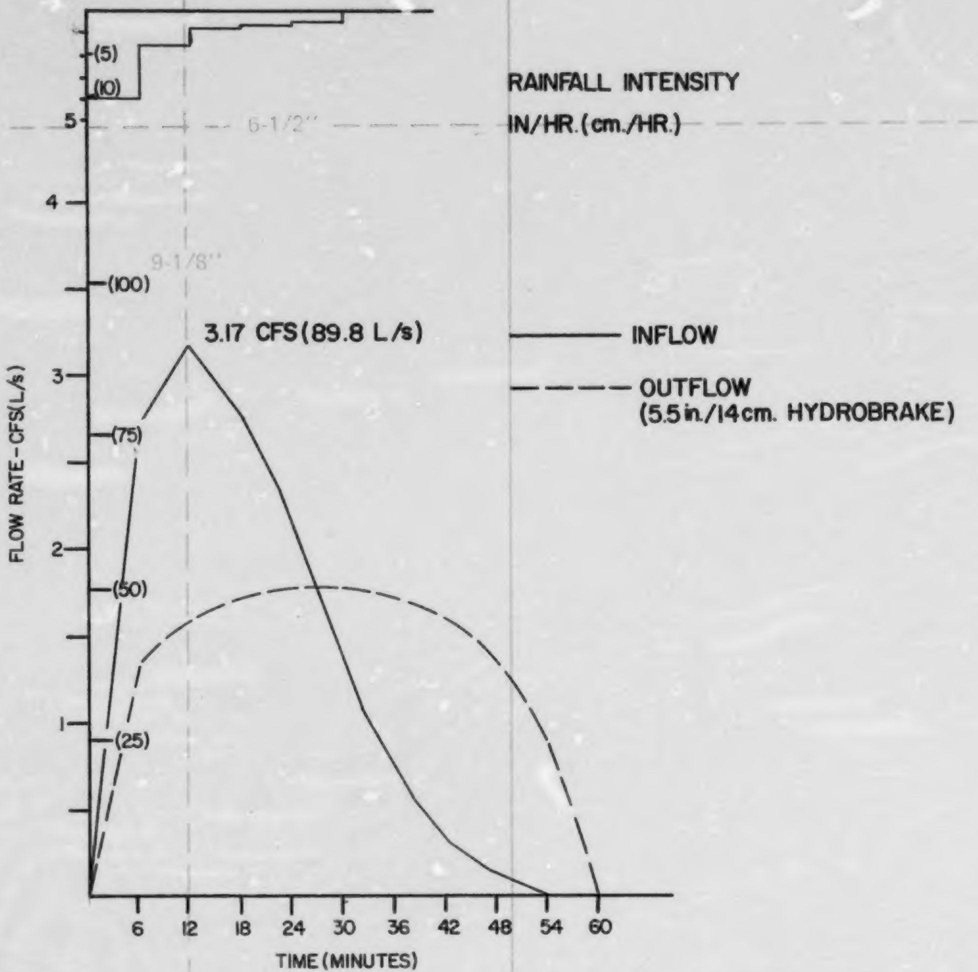

FIGURE E-12 PURITAS AVE. DESIGN STORM HYDROGRAPHS
1YR. RETURN – 1/2 HR. DURATION (76 in.–1.93 cm.)

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APPENDIX F

HYDRO BRAKE/RETENTION APPLICATIONS IN CLEVELAND, OHIO DESIGN CRITERIA AND PROJECT SUMMARIES

by
City of Cleveland
Department of Public Utilities

Narrative Sections
by
J. Christopher Kocsan

Technical Sections
by
Francis Toldy, P.E.

INTRODUCTION

The purpose of this appendix is three (3) fold. First, the City of Cleveland has recently constructed many projects which are similar in nature to the evaluated grant project. The City intends, at this point, to present descriptions of each of these similar projects, including pertinent statistical data, and to compare and contrast these similar projects to the evaluated grant project.

Secondly, during the evaluation of the grant project, it became obvious to all concerned parties that the underground retention tanks which had been constructed were not being fully utilized as far as their storage capacities were concerned. Accordingly, new more restrictive Hydro-Brake flow regulators were installed within these tanks during the summer of 1981. The manner in which these new sizes were determined by the City, is presented within this section of the appendix.

The final section of this appendix contains a Design Manual for Storm Water Retention Facilities. The City has taken one of its similar projects, and by using that project as an example, it has demonstrated on a step-by-step basis the manner in which an interested party would proceed with designing this type of Storm Water Retention Facilities. It is believed that the information contained within this section will prove quite valuable to those readers who are interested in constructing projects similar to the one which has just been evaluated.

COMPARISON OF SIMILAR PROJECTS

A comparison of the similar projects which have been constructed by the City of Cleveland since the time when the evaluated grant project became operational will now be presented.

1. Southwest Sewer Project - Phase I

The Southwest Sewer Project - Phase I is a project in which the City of Cleveland utilizes an existing creek within the project area to receive excess storm water flow which has been created by heavy rains. The City has achieved this by installing thirteen (13) 4-inch Standard Hydro-Brake flow regulators within the existing catch basins which are located at the uphill ends of Kirton Avenue. The flow out of these catch basins has been greatly reduced because of the installation of this patented control device. Accordingly, since during periods of heavy storms, the flow into these combined sewers is retarded by the installed Hydro-Brakes, and since these catch basins are also located at the uphill ends of Kirton Avenue, a majority of the storm water run-off is bypassing the uphill catch basins and flowing into the catch basins which are located in the low point area of Kirton Avenue. These catch basins discharge their flow directly into the existing creek.

The Hydro-Brakes which were recently installed possess a discharge rating of .25 CFS at three (3) feet of head. A total of $8,450 was expended by the City for the purchase of Hydro-Brakes concerning this project, as these Hydro-Brakes cost $650 each, including installation. The total drainage area along Kirton Avenue which is effected by the installation of these Hydro-Brakes is approximately four (4) acres.

Since the project contained a number of different improvements in addition to the Hydro-Brake installations, it is not appropriate to discuss a per cubic foot cost as far as storage space is concerned. The construction cost of this project was $83,487. In addition, because of the referenced additional improvements, it is also not appropriate to quote a figure concerning the cost per acre required in order to implement this project.

The major element of the additional improvements which were made, above and beyond the installation of the referenced Hydro-Brakes, was the rebuilding of sixteen (16) existing catch basins located within the low point areas of three streets - Kirton Avenue, Carrington Avenue and Erwin Avenue. The storm flow from these catch basins was rerouted from the existing combined sewer system into a nearby creek. This obviously reduced the level of flow to the combined system within the area. In addition, a small playground within the area was enlarged and landscaped, and it is now used as an above ground storm water re tention basin during periods of intense rainfall and sewer system sur charging.

2. Southwest Sewer Project - Phase II

The Southwest Sewer Project - Phase II is quite similar to the evaluated grant project. In this project, the City constructed four (4) underground storm water retention tanks within the project area, as well as utilizing the available roadway surface for purposes of storm water storage during periods when intense rainfalls cause the combined sewer system in the area to become surcharged. A summary of the characteristics of the four undergound retention tanks which were constructed is as follows:

	LOCATION	DIMENSIONS	CAPACITY	OUTLET REGULATOR	OUTLET DISCHARGE RATE
1.	Crossburn Ave.	353' Long 48" Dia.	4,436 Cu. Ft.	6" Standard Hydro-Brake	0.6 CFS @ 5 Ft. of Head
2.	Crossburn Ave.	400' Long 48" Dia.	5,026 Cu. Ft.	6" Standard Hydro-Brake	0.6 CFS @ 5 Ft. of Head
3.	Bennington Ave.	400' Long 48" Dia.	5,024 Cu. Ft.	6" Standard Hydro-Brake	0.6 CFS @ 5 Ft. of Head
4.	Bennington Ave.	371' Long 48" Dia.	4,662 Cu. Ft.	9" Standard Hydro-Brake	1.5 CFS @ 5 Ft. of Head

All tanks were constructed of corrugated steel pipe, are circular in diameter, and were positioned at low points on their respective streets. A total of 13 catch basins along Crossburn Avenue now have their storm flow diverted into the two newly constructed retention tanks instead of directly into the combined sewer system. A total of 14 catch basins along Bennington Avenue have their storm flow diverted in a similar manner. All of the retention tanks eventually discharge their storm flow through the Hydro-Brakes and into the existing combined sewer system at the controlled rate of discharge which is regulated by the Hydro-Brake.

A total of five (5) existing catch basins within the project area have been equipped with four-inch Standard Hydro-Brakes in order to increase the level of storm water runoff flowing towards the low points of the referenced streets. At this point, the surface runoff from the area is dischargeed directly into the retention tanks through the low point catch basins. These Hydro-Brakes have discharges which are rated by the manufacturer at .25 CFS at 3 feet of head.

The construction cost of the entire project was $175,860. The project effects a total drainage area of 38.6 acres. Thus, the project cost $4,556 per acre in order to construct. The total volume of storage which is available within the constructed retention tanks is 19,175 cubic feet. Thus, the project cost $9.17 for every cubic foot of storage space created.

The costs pertaining to the purchase of the required Hydro-Brakes for this project, including installation, were as follows:

Description	Quantity	Price	Extension
9" Standard Hydro-Brake	1	$2,300	$2,300
6" Standard Hydro-Brake	3	1,675	5,025
4" Standard Hydro-Brake	5	915	4,575
		Total	$11,900

Thus, a total of $11,900 was expended by the City within the applicable construction contract for the purchase and installation of Hydro-Brakes concerning this project.

3. Southwest Sewer Project - Phase III

This project, as far as scope of work is concerned, is a combination of the preceding two phases of this four phase series of projects. Within this phase, the City constructed one underground retention facility along West 127th Street between Astor and Crossburn Avenues. The referneced tank is 209 feet long, is 66 inches in diameter, and has a capacity of 4,965 cubic feet. The tank's outlet is equipped with a 6-inch Standard Hydro-Brake which has a discharge rating of .7 CFS at 5 feet of head.

A total of seven (7) catch basins in the area have their flow diverted into the newly constructed retention tank. In addition, four other catch basins within the project area have also been equipped with 4-inch Standard Hydro-Brakes which possess discharge ratings of .25 CFS at 3 feet of head. This further relieves the level of storm flow which enters the combind sewer system during periods of sewer surcharging. Because of the implementation of this system, the number of incidents of surcharging within the project area have been effectively reduced. The total drainage area which is tributary to the constructed retention tank is 3.3 acres.

The total expenses incurred by the City for the purchase of Hydro-Brakes, including installation, concerning this project is as follows:

Description	Quantity	Price	Extension
6" Standard Hydro-Brake	1	$1,800	$1,800
4" Standard Hydro-Brake	4	1,050	4,200
		Total	$6,000

Thus, a total of $6,000 was expended for the purchase and installation of Hydro-Brakes concerning this project.

Along Longmead, Milligan and McGowan Avenues, which are adjacent streets located within the project area, thirteen (13) existing catch basins were reconstructed with their storm flow being rerouted from the area's existing combined sewer system into a nearby creek. This further reduces the storm flow entering the combined system within the area.

Because of these additional improvements, it is improper to quote a project cost based upon per acre of drainage area effected. It is also improper to quote a cost per cubic foot of storage space created. The construction cost of the project was $83,267, while the total drainage area effected by all elements of the project is 8.5 acres.

4. Southwest Sewer Project - Phase IV

Within this project, the City constructed two (2) underground storm water retention tanks at low points along Carrington Avenue. The first of these tanks is 300 feet long, 48 inches in diameter, and has a volume of 3,770 cubic feet. The tank is not equipped with a Hydro-Brake regulator, but with a discharge pipe which is six-inches in diameter and which discharges its storm flow into an existing 18-inch combined sewer.

The second tank is slightly smaller. It is 250 feet long, 48 inches in diameter, and has a volume of 3,142 cubic feet. This tank is also equipped with a discharge pipe which is six-inches in diameter, but which discharges its flow into a 20-inch combined sewer. Both tanks are constructed of corrugated steel pipe. A total of eight catch basins now discharge their storm flow into these two retention tanks.

None of the catch basins which are located uphill from the two retention tanks constructed along Carrington Avenue are equipped with Hydro-Brakes.

The total storage volume created by the project is 6,912 cubic feet, with a cost per cubic foot of storage space created equaling $7.60. The total drainage area effected by the project is 16.1 acres. The cost per acre effected was $3,621. No funds were expended for the purchase of Hydro-Brakes concerning this project.

5. Retention Catch Basin Demonstration Project
Phase I-A

This project is a continuation of the Storm Water Quality Control Program which was implemented by the City of Cleveland under the authority of this grant.

This project included the installation of 12 Hydro-Brakes in existing Catch Basins just north of the area affected by the evaluated grant project. These Hydro-Brakes were installed within catch basins located along Milburn Avenue, West 168th Street, West 171st Street, West 173rd Street and West 176th Street. The purpose of these installations was to allow the excess storm runoff to bypass the uphill catch basins so that the runoff is collected at the street's low point. Eventually, this flow will be directly discharged into the new storm sewer referenced within the following paragraph.

The project also included the installation of a new storm sewer in Milburn Avenue and West 168th Street. This new sewer was connected into an existing 78 inch sewer, thus eliminating the need for constructing underground retention facilities along either street. A total of 12 catch basins were rerouted from the combined system into the newly constructed storm sewer, thus providing relief to the existing combined sewer system and reducing the number of incidents of sewer surcharging in the area. The construction cost of the entire project was $100,508, and the drainage area serviced by the project is 12.8 acres.

As stated previously, a total of 12 Hydro-Brakes were installed within existing catch basins in order to utilize the roadway surfaces for storm water ponding, thus reducing combined sewer surcharging. The expenses incurred by the City within the applicable construction contract for the purchase and installation of these Hydro-Brakes were as follows:

Description	Quantity	Price	Extension
4" Standard Hydro-Brake	2	$600	$1,200
2" Standard Hydro-Brake	10	290	2,900
		Total	$4,100

Thus, a total of $4,100 was expended by the City for the purchase and installation of Hydro-Brakes concerning this project. Because of the additional improvements above and beyond the installation of the referenced Hydro-Brakes, the quoting of costs based upon per acre of area serviced or cubic foot of storage created concerning this project is irrelevant.

Summary of Projects 1 through 5

The sewage flow from all five project areas is eventually discharged into the 8 foot combined sewer which services West 130th Street and which flows in a northerly direction. This sewer terminates at Brooklawn Avenue where the excess flow from the combined sewer is allowed to overflow into a dual 12 foot by 8 foot storm sewer. This occurs during periods when the 8 foot combined sewer is surcharged. During dry weather, when no excess flow exists, the flow from the 8 foot combined sewer flows directly into a No. 5C sanitary line. (Please see Table C)

The Southwest Sewer Projects - Phases I through IV, are geographically located near the Brooklawn Avenue Combined Sewer Overflow. This means that these four projects, some of which include the storage of storm water and thus reduce the level of flow within the West 130th Street sewer, should have had a positive impact upon the quality of water which is routed into the streams and rivers within the area. It is believed that these projects have reduced the number of overflow occurrences, as well as reducing the volume of combined sewage which overflows at this location. Although the City assumes this to be the situation, because it is the most logical result of the implementation of these projects, it has not been verified, as neither formal monitoring of the overflow nor a post construction evaluation study have been undertaken concerning these projects. The City does not presently plan to undertake a post construction evaluation of Projects

1 through 5 as funds are rather limited and are not currently available for these purposes.

The sewage flow effected by the Retention Catch Basin Demonstration Project Phase 1-A is also eventually routed into the West 130th Street sewer. However, because the location of this project is somewhat removed from the overflow in question, its impact upon that overflow is not quite as profound or measurable as the impact of the Southwest Sewer Projects, Phases I through IV. Nevertheless, the effect of this project on water quality within the area should not be underestimated as the project directly effects the combined sewer overflow which is located near the intersection of Puritas Avenue and Interstate 71 (M-15), as well as indirectly effecting the performance of the Brooklawn Overflow.

It does appear that the basement flooding within these areas has been drastically reduced by the construction of these projects. While the City used to receive many complaints from the residents of these areas, the present rate of complaints from these areas regarding basement flooding has been reduced to a minimal level. It also does not appear that street flooding has become a problem in the areas where Hydro-Brakes were installed within the existing catch basins in order to utilize surface storage technology. Overall, the projects seem to have had a positive impact upon the areas which they service and the City is quite pleased with the results which have been generated by the projects.

6. Hamlet Avenue Sewer Project - Phase II

The City of Cleveland constructed one retention tank in the sidewalk area of Hamlet Avenue within the scope of this project. The tank which was constructed is 467 feet in length, 48 inches in diameter, and contains a volume of 5,868 cubic feet of storage space for purposes for storing storm water runoff. The tank discharges through an outlet pipe which is 6-inches in diameter and into an existing No. 3 brick sewer. (Please see Table C) The tank is constructed of corrugated steel pipe and a total of five catch basins presently have their flow routed into the referenced tank.

The project services a drainage area which encompasses two acres. The project's construction cost was $46,509, while the project cost $7.93 for every cubic foot of storage space created. The project can also be considered to cost $23,255 per acre of area serviced. No funds were expended for the purchase of Hydro-Brakes concerning the project, as none were installed at this location.

7. Adolpha Avenue Retention Facility

Approximately one year after the completion of the Hamlet Avenue Sewer Project - Phase II, it became apparent to the City that the completion of the referenced project had not solved all of the basement and street flooding problems which were present within the area. At that time, the City's Department of Public Utilities began to research different alternatives which would lead to the elimination of all of the problems present within the area. It was at this time that the City developed and decided to construct a project which is now known as the Adolpha Avenue Retention Facility.

The Adolpha Avenue Retention Facility is an underground storm water retention tank which was constructed in two sections. The first section is 280 feet in length, 48 inches in diameter, and has a storage volume of 3,518 cubic feet. The second section is 232 feet in length, 60 inches in diameter, and has a storage volume of 4,555 cubic feet. Total storage volume of the entire tank is 8,073 cubic feet and the entire tank is constructed of Corrugated Steel Pipe.

The tank discharges its flow through a 12inch outlet which is equipped with a 4-inch Standard Hydro-Brake. This flow regulator has a discharge rating of .25 CFS @ 3 feet a head. The total amount expended by the City within the construction contract for the purchase of this Hydro-Brake was $300, including installation. The tank discharges its flow into an existing No. 5 brick sewer. (Please see Table C)

A total of seven catch basins, five of which were existing and two of which were recently constructed, have their flow routed into the referenced retention tank. The total drainage area which is tributary to the retention facility is 2.9 acres. The project's construction cost was $58,260. Thus, to express expenses in comparative terms, the project cost $20,090 per acre of area affected or $7.22 per cubic foot of storage space created.

Summary of Projects 6 and 7

The retention tanks constructed in Hamlet and Adolpha Avenues discharge their flows into the existing Hamlet - Adolpha Sewer. This sewer then carries the flow into the No. 12 sewer running along East 65th Street. (See Table C) The East 65th Street Sewer is the main interceptor sewer for the area and it flows in a northerly direction.

There is a combined sewer overflow located0.7 of a mile north of the point where the Hamlet - Adolpha Sewer introduces its flow into the East 65th Street Sewer. This overflow is located at the intersection of East 65th Street and Selma Avenue. However, because of the large capacity available within the East 65th Street Sewer, and because of the large number of small sewers which are tributary to the East 65th Street Sewer, it is nearly impossible to measure the positive effects which these two projects have had upon the overflow under consideration, and formal attempts to do so have not been undertaken.

It does appear that the basement and street flooding problems which were prevelant within the area have been reduced by the construction of these two projects, as complaints to the City of this nature have been reduced to minimal levels within the past year. Prior to this, complaints of this nature were quite common as levels of street and basement flooding sometimes reached 18 inches. Thus, the City is quite pleased with the results of the two projects, as a severe problem has been eliminated with minimal capital expense to the City.

8. East 99th Street and Carr Avenue Area Retention Facilities

This project is also quite similar in nature to the evaluated grant project. The project included the construction of three storm water retention tanks at low points within a 12.3 acre drainage area. Two tanks were constructed along Carr Avenue, while one tank was constructed along East 99th Street. All three tanks were constructed of corrugated steel pipe and the total storage volume created by the construction of these tanks is 8,467 cubic feet.

The two tanks constructed along Carr Avenue both discharge their flow into a common manhole with a 12-inch outlet pipe which is equipped with a 7-inch Standard Hydro-Brake. This Hydro-Brake has a discharge rating of .9 CFS @ 5 feet of head and the City expended $1,220 for the purchase of the subject Hydro-Brake, including installation, within the project's construction contract.

The larger of the two tanks constructed along Carr Avenue is 230 feet in length, 48 inches in diameter, and has a volume of 2,880 cubic feet. The smaller of the two tanks is 100 feet long, 48 inches in diameter and has a storage volume of 1,257 cubic feet. The total storage volume which discharges through a 12-inch outlet pipe, and which is regulated by a 7-inch Standard Hydro-Brake, is 4,147 cubic feet. A total of six (6) catch basins now have their flow routed into the two retention tanks which are under consideration. The tanks in question discharge their storm flow into an existing No. 6 brick sewer. (Please see Table C)

The tank which was constructed along East 99th Street is 220 feet in length, 60 inches in diameter, and has a storage volume of 4,320 cubic feet. A total of three (3) catch basins located along East 99th Street now have their storm flow diverted away from the combined sewer system and into the referenced retention facility. The tank discharges its flow through a 12-inch outlet pipe which is equipped with 5-inch Standard Hydro-Brake. This Hydro-Brake has a discharge rating of .5 CFS @ 5 feet of head and cost the City $950 to install, including installation. The flow from the referenced facility is discharged into an existing No. 3 brick sewer. (Please see Table C)

The total cost incurred by the City for construction of this project was $83,202. A total of 12.3 acres of drainage area was effected by the construction of the project. This project cost the City $6,474 per acre of drainage area effected. The project also cost the City $9.83 per cubic foot of storage space created.

A post-construction evaluation of the referenced project has not been undertaken. However, preliminary indications are that the project has had a positive effect upon the combined sewer system within the area and that basement flooding has been drastically reduced.

9. Parkridge Avenue Retention Facility

Within this small project, the City of Cleveland constructed one (1) underground storm water retention tank along Parkridge Avenue. The tank which was constructed is 300 feet in length, 48 inches in diameter, has a storage volume of 3,770 cubic feet, and is constructed of Corrugated Steel Pipe. The flow from two catch basins within the area has been routed away from the combined sewer system and into the referenced retention tank.

The tank discharges its flow through an outlet pipe which is 6-inches in diameter and into an existing 15-inch combined sewer. The tank's outlet is not equipped with a Hydro-Brake.

The project cost $29,018 to construct while the total drainage area which is tributary to the referenced tank is 4 acres. Thus, the project cost $7.70 per cubic foot of storage space created and $7,254 per acre of drainage area effected. The City has received many positive responses from the area's residents concerning this project.

10. Lakeview Road Area Retention Facilities

The last of the projects which will be analyzed within this appendix is the Lakeview Road Area Retention Facilities. Once again, this project is very similar to the evaluated grant project. The project included the construction of three underground storm water retention tanks along cross streets which intersect Lakeview Road. The project also included the strategic placement of Hydro-Brakes within exsiting catch basins in order to take advantage of the roadway surface storage capacity which is available within the project area.

The first of these tanks, which was constructed along Ohlman Avenue, is 384 feet in length, 48 inches in diameter, has a storage capacity of 4,826 cubic feet, and is constructed of Reinforced Concrete Pipe. The flow from six (6) catch basins has been diverted into this tank.

The tank discharges its flow through a 12-inch outlet pipe which is equipped with a 5-inch Standard Hydro-Brake and into a 15-inch combined sewer. The tank's Hydro-Brake has a discharge rated at .5 CFS @ 5 feet of head and cost $1,075, including installation.

Two catch basins located along Ohlman Avenue which are uphill from the retention tank have been equipped with Standard 2-inch Hydro-Brakes in order to allow additional storm water runoff to be captured by the catch basins located within the low points of Ohlman Avenue. The discharge of these Hydro-Brakes is rated at .06 CFS @ 3 feet of head and the subject Hydro-Brakes cost $500 each, including installation.

The second tank, which was constructed along Saywell Avenue, is 428 feet in length, 48 inches in diameter, has a storage capacity of 5,378 cubic feet and is constructed of Corrugated Steel Pipe. The flow from six (6) catch basins within the area is discharged into the referenced tank instead of entering the combined sewer system. The tank discharges its flow through a 12-inch outlet pipe which has been equipped with a 5-inch Standard Hydro-Brake and into an existing 18-inch combined sewer. The tank's Hydro-Brake has a discharge rated at .5 CFS @5 feet of head by the manufacturer and cost $1,075, including installation.

In addition, two catch basins located along Saywell Avenue have also been equipped with Standard 2-inch Hydro-Brakes in order to allow additional storm water runoff to be captured at the catch basins located within the low point of Saywell Avenue. These Hyrdo-Brakes have a discharge rated at .06 CFS @ 3 feet of head and cost $500 each including installation.

The third tank was constructed along Fairport Avenue. This tank is 325 feet in length, 48 inches in diameter, has a storage capacity of 4,084 cubic feet, and is constructed of Reinforced Concrete Pipe. A total of 6 catch basins now have their flow diverted into the retention tank. The flow from the retention tanks is then discharged through a 12-inch outlet which is equipped within a 5-inch Standard Hydro-Brake and into an existing 15 inch combined sewer. The Hydro-Brake which has been utilized has a discharge rated at .5 CFS @ 5 feet of head and cost $1,075 including installation.

As with the other two streets, two catch basins along Fairport Avenue were equipped with 2-inch Standard Hydro-Brakes in order to aid in the capturing of additional surface runoff in the low point area of Fairport Avenue. The Hydro-Brakes which were installed have a discharge rating of .06 CFS @ 3 feet of head and cost $500 each including installation.

The construction cost of this project was $177,143. A total of 19.3 acres of drainage area are effected by the project. The total volume of storage space now available because of the construction of the three retention tanks is 14,288 cubic feet. Thus, the project cost $12.40 for every cubic foot of storage space created, and $9,178 per acre of drainage area effected.

Summary of Projects 8 through 10

These three projects are somewhat different than the previously considered projects in that the effect which these projects have upon Combined Sewer Overflows is minimal. The construction of the East 99th Street and Carr Avenue Retention Facilities did not effect the level of combined sewage flowing into Lake Erie in any manner, as the storage capacity which was created by the project is not sufficient to have any effect upon the nearest Combined Sewer Overflow, which is located 1,050 feet to the west along East 88th Street. The project was undertaken with the intention of reducing basement flooding in an area where this problem was being experienced on a wide spread scale. With the construction of the project, this problem has been almost completely eliminated, as virtually no complaints are being received from this area concerning this problem which has plagued this area in the recent past.

The construction of the Parkridge Avenue Retention Facility also has a minimal effect upon the level of combined sewage overflowing into Lake Erie. The nearest Combined Sewer Overflow is located 1,300 feet south of the project, where a 48 inch combined sewer intersects with the six (6) foot Big Creek Interceptor. The retention capacity created by the construction of a single retention tank on Parkridge Avenue does not create enough storage volume to have a significant impact upon the referenced overflow. Once again, the intention of the City in constructing this project was to eliminate basement flooding in an area which was badly affected by this problem, and the elimination or reduction of combined sewer overflows was only a secondary consideration.

The construction of the last project to be considered, the Lakeview Road Retention Facilities, most probably had a profound effect upon the nearest Combined Sewer Overflow, which is located at the intersection of Lakeview Road and Hopkins Avenue, just three blocks north of the project area. Because of the large volume of storage capacity created by the project, it is anticipated that the level of and the number of occurences of combined sewer overflows at this location has been drastically reduced. However, without the benefit of a post - construction evaluation concerning the referenced project, it is impossible to quantify and verify that a reduction in the level and the number of overflows occuring at this location has taken place.

As with the other two projects, the construction of the Lakeview Road Area Retention Facilities has virtually eliminated the basement flooding problem which was prevelant within the project area prior to construction. Due to lack of funds, an evaluation of the effect which this project has had upon the nearest Combined Sewer Overflow can not be undertaken at this point in time.

General Comments

It may appear from the information given within the preceeding text, as well as from the information given within Table A and Table B, which immediately follows these comments, that the installation of Hydro-Brakes significantly increases the cost of a project as far as the acreage of drainage area effected, as well as the cost per cubic foot of storage space created. For example, from the projects which are cited, those projects which do not utilize Hydro-Brakes cost approximately $7.50 per cubic foot of storage space created, while the cost per cubic foot of storage space created for those projects which do utilize Hydro-Brakes ranges from $9 to $12. In addition, for those projects cited, the cost per acre of drainage area effected for projects which utilize Hydro-Brakes is generally higher than the cost per acre of drainage area effected for projects which do not utilize Hydro-Brakes.

This may lead the reader to believe that the utilization of Hydro-Brakes within a project significantly increases the cost of that project. In fact, this is not the case. The reader should notice from the text of the appendix, as well as from the information contained within Table A, that the actual cost of Hydro-Brake regulators on a per unit basis is rather insignificant. It should also be noted that concerning those projects in which multiple Hydro-Brakes have been utilized, the cost of these units is rather insignificant when compared to the total construction cost of the project. Therefore, it is purely coincidental that the cost per acre of drainage area effected, as well as the cost per cubic foot of storage space created, appears to be significantly higher for those projects which utilize Hydro-Brakes than for those projects which do not.

The reader may have also noted from the text of this appendix, as well as from the information given within Table A, that it appears that from project to project, the price of Hydro-Brakes flucuates widely even though the sizes of Hydro-Brakes used within the projects may be equivalent. The reason for this phenomenon is the fact that the prices quoted for Hydro-Brakes within this report are the prices which were bid by the various contractors who constructed the projects. The prices for these units within each of the applicable construction contracts contain may different elements such as the actual cost of the device, overhead, profit, etc. The inclusion of these considerations within the prices quoted by the various contractors for the purchase and installation of these control devices makes it impossible to quote the actual price which was paid for the purchase and installation of Hydro-Brakes within each of these projects.

TABLE A

COMPARATIVE SUMMARY OF EVALUATED PROJECTS

	PROJECT TITLE	METHOD OF STORAGE	VOLUME OF STORAGE	OUTLET REGULATOR	COST OF REGULATOR	CATCH BASINS REGULATED	CATCH BASIN REGULATOR	COST OF REGULATOR
1.	Southwest Sewer Project Phase I	Surface Ponding	N/A	N/A	N/A	13	4" Standard Hydro-Brakes	$ 650 Each
2.	Southwest Sewer Project Phase II	4 Retention Tanks Plus Surface Ponding	19,148 Cu. Ft.	One 9" Standard Hydro-Brake and Three 6" Standard Hydro-Brakes	$ 2,300 Each 1,675 Each	5	4" Standard Hydro-Brakes	$ 915 Each
3.	Southwest Sewer Project Phase III	1 Retention Tank Plus Surface Ponding	4,965 Cu. Ft.	One 6" Standard Hydro-Brake	$ 1,800 Each	4	4" Standard Hydro-Brake	$ 1,050 Each
4.	Southwest Sewer Project Phase IV	2 Retention Tanks Plus Surface Ponding	6,912 Cu. Ft.	Two 6" Orifices	N/A	0	N/A	N/A
5.	Retention Catch Basin Demonstration Project Phase IA	Surface Ponding	N/A	N/A	N/A	12	Two 4" Standard Hydro-Brakes and Ten 2" Standard Hydro-Brakes	$ 600 Each $ 290 Each
6.	Hamlet Avenue Sewer Project Phase II	1 Retention Tank	5,868 Cu. Ft.	One 6" Orifice	N/A	0	N/A	N/A
7.	Adolpha Avenue Retention Facilities	1 Retention Tank	8,073 Cu. Ft.	One 4" Standard Hydro-Brake	$ 300 Each	0	N/A	N/A

TABLE A

COMPARATIVE SUMMARY OF EVALUATED PROJECTS (Continued)

PROJECT TITLE	METHOD OF STORAGE	VOLUME OF STORAGE	OUTLET REGULATOR	COST OF REGULATOR	CATCH BASINS REGULATED	CATCH BASIN REGULATOR	COST OF REGULATOR
8. East 99th Street & Carr Ave. Retention Facilities	3 Retention Tanks	8,467 Cu. Ft.	One 7" Standard Hydro-Brake and One 5" Standard Hydro-Brake	$ 1,220 Each $ 950 Each	0	N/A	$ N/A
9. Parkridge Avenue Retention Facilities	1 Retention Tank	3,770 Cu. Ft.	One 6" Orifice	N/A	0	N/A	N/A
10. Lakeview Road Area Retention Facilities	3 Retention Tanks Plus Surface Ponding	14,288 Cu. Ft.	Three 5" Standard Hydro-Brakes	$ 1,075 Each	6	2" Standard Hydro-Brake	$ 500 Each

TABLE 8

COST SUMMARY
OF
EVALUATED PROJECTS

	PROJECT TITLE	PROJECT COST	DRAINAGE AREA EFFECTED	PROJECT COST PER ACRE	STORAGE SPACE CREATED	COST PER CUBIC FOOT OF STORAGE SPACE CREATED
1.	Southwest Sewer Project Phase I	$ 83,487	4.0 Acres	N/A	N/A	N/A
2.	Southwest Sewer Project Phase II	$ 175,860	38.6 Acres	$ 4,556	19,148 Cu. Ft.	$ 9.18
3.	Southwest Sewer Project Phase III	$ 83,267	8.5 Acres	N/A	4,965 Cu. Ft.	N/A
4.	Southwest Sewer Project Phase IV	$ 53,503	16.1 Acres	$ 3,621	6,912 Cu. Ft.	$ 7.60
5.	Retention Catch Basin Demonstration Project Phase IA	$ 100,508	12.8 Acres	N/A	N/A	N/A
6.	Hamlet Avenue Sewer Project Phase II	$ 46,509	2.0 Acres	$ 23,255	5,868 Cu. Ft.	$ 7.93
7.	Adolpha Avenue Retention Facilities	$ 58,260	2.9 Acres	$ 20,090	8,073 Cu. Ft.	$ 7.22
8.	East 99th Street & Carr Ave. Retention Facilities	$ 83,202	12.3 Acres	$ 6,474	8,457 Cu. Ft.	$ 9.84
9.	Parkridge Avenue Retention Facilities	$ 29,018	4.0 Acres	$ 7,254	3,770 Cu. Ft.	$ 7.70
10.	Lakeview Road Area Retention Facilities	$ 177,143	19.3 Acres	$ 9,178	14,288 Cu. Ft.	$ 12.40

TABLE C

COMPARISON BETWEEN CITY OF CLEVELAND EGG SHAPED BRICK SEWER SIZES AND PRESENT DAY SEWERS WHICH ARE CIRCULAR IN DIAMETER

EGG SHAPED SEWER REFERENCE NUMBER	WATER WAY AREA IN SQUARE FEET	EQUIVALENT CIRCULAR SIZE IN INCHES
1	1.00	15
2	2.52	21
3	4.33	27
4	6.35	33
5	8.55	36
6	10.90	42
7	13.39	48
8	16.00	54
9	18.72	60
10	21.54	N/A
11	24.46	66
12	27.47	72
13	30.57	N/A
14	33.74	78

Letter suffixes which are added to sewer reference numbers denote the following type of construction:

A - 1 Ring of brick around

B - 1 Ring of brick around, 1 extra ring on arch

C - 2 Rings of brick around

D - 2 Rings of brick around, 1 extra ring on arch

E - 3 Rings of brick around

HYDRO BRAKE RESIZING DECISION

As stated previously within the main body of this report, during the course of the post-construction evaluation of the demonstration grant project, it became evident to all concerned parties that the retention facilities which had been constructed were not being utilized in an efficient manner. Specifically, a large percentage of the storage volume created by the construction of the three retention tanks was never being utilized. This situation was verified by the fact that during the course of 1980, the storm water which was captured and stored within these retention tanks never reached a depth which exceeded a few inches.

It was apparent to the City that one of the following three factors was adversely effecting the performance of the referenced retention tanks:

A) The retention tanks which were constructed were too large and were oversized.

B) The drainage areas which were tributary to each of the retention tanks were too small to capture enough storm flow to utilize the storage space available within these tanks.

C) The Hydro-Brakes which had been installed within each of the tanks' outlets at the recommendation of the designer did not restrict the discharge of the tanks sufficiently in order to take advantage of the storage capacity which had been created.

It was fairly obvious that since the facilities had already been constructed, Factors A and B could not be altered except at great expense to the City. For that reason, Factors A and B were considered as given.

Because of this situation, the City decided to attempt to modify Factor C so that the retention tanks which had been constructed would be utilized more efficiently, thus taking advantage of the storage capacity which had been created. In order to do this, the City decided that the Hydro-Brakes within each of the tanks' outlets should be removed and replaced with Hydro-Brakes which were more restrictive in terms of their discharge. This decision was made early during 1981, with the installation of the more restrictive Hydro-Brakes tentatively scheduled for May 1, 1981.

As indicated within the main body of this report, problems were experienced with the delivery of the new Hydro-Brakes which were selected by the City for installation within the retention tanks. After numerous delays, these devices were finally received and installed in mid-summer of 1981. This provided the City and its consultant a minimal period for evaluating and monitoring the performance of the referenced Hydro-Brakes. It should be pointed out, however, that during the period of time in which the Hydro-Brakes were being evaluated, much meaningful data was gathered. This data has subsequently been considered within preceeding sections of this report.

Prior to the City's decision to select alternative sizes of Hydro-Brakes for installation, it was necessary for the City to make a number of assumptions in order to be able to select those Hydro-Brakes which were of a proper size and which possessed an appropriate discharge rating. The assumptions which were made are as follows:

1. The areas from building set-back line to building set-back line are tributary to the retention tanks.
2. The discharge of all Hydro-Brakes was assumed to be relatively constant.
3. The Hydro-Brakes which were installed within the existing catch basins, and which discharge their flow directly into the combined sewer system, were not taken into consideration during the course of this evaluation. The reason why these Hydro-Brakes which had been installed within the existing catch basins were not taken into consideration is because the level of impact which these units have upon the volume of storage space utilized within the constucted retention tanks is minimal.
4. The volumes of the retention tanks as computed by Snell Environmental Group were assumed to be correct.

Having made the preceeding assumptions, the City then used the following methodology in order to arrive at its decision to request that the manufacturer replace the originally selected Hydro-Brakes with Hydro-Brakes which were smaller, and more restrictive, in terms of their discharge rating.

1. Areas which are tributary to each of the retention tanks were calculated. (Table D)
2. The various drainage areas effected by the project were evaluated for various storm frequencies of one (1) hour duration. (Table E). Following this analysis, the drainage areas were then evaluated for ten (10) year storms of various durations. (Table F). The one (1) hour, ten (10) year storm produced the largest volume of storage utilized within the retention tanks. It was determined that using this storm as a design criteria was far superior to using any other design criteria which had previously been recommended.
3. Hydrographs for a ten (10) year, one (1) hour storm were then developed for each drainage area. (Figures 1, 2, 3). A relationship between hydrograph volume and the rate of discharge was then developed to utilize the existing storage volume of the retention tanks located within the drainage areas.
4. Hydrographs for a five (5) year, one (1) hour storm duration were then developed for comparative purposes. (Figures 4, 5, and 6).

From the various hydrographs which were developed, the City was able to determine which Hydro-Brake discharge rates would provide maximum utilization of the storage space which is available in the constructed retention tanks. In order to make this determination, a 10 year storm of one hour duration was selected as a design criteria for the previously mentioned reasons.

Having selected the design criteria, the Engineering Section of the City's Division of Water Pollution Control moved forward with its attempt to determine the sizes and discharge rates of Hydro-Brakes which would utilize the storage space which had been created in an efficient manner. A trial and error methodology was used in that calculations of the volumes of storage space utilized for each retention tank were computed under Hydro-Brakes of various sizes and possessing various discharge ratings. Results were compared, and those Hydro-Brakes which provided the largest volume of storage space utilization, that is, those Hydro-Brakes which stored the greatest volume of storm water runoff without creating a maintenance problem, were chosen for installation.

The characteristics and capacities of each retention tank were considered independently during the course of the analysis. The Engineering Section of the Division of Water Pollution Control arbitrarily determined that any Hydro-Brake which possessed a discharge rating of less than .25 CFS would be a maintenance problem because of clogging and possible blockage. Taking these factors into consideration, the existing retention tanks were modified by the installation of new Hydro-Brakes. The following is a summary of the characteristics of these retention tanks after the new Hydro-Brakes had been installed, including a summary of the tank's expected level of performance during a ten year storm of one hour duration.

1. West 177th Street Tank

   Regulator: 3" Hydro-Brake
   Discharge rating: .25 CFS

   Capacity of Retention Tank: 8,984 cubic feet
   Volume of water stored: 7,900 cubic feet
   Excess capacity: 1,084 cubic feet

2. Puritas Avenue Tank

   Regulator: 5.5" Hydro-Brake
   Discharge rating: 1.0 CFS

   Capacity of Retention Tank: 6,024 cubic feet
   Volume of water stored: 5,000 cubic feet
   Excess capacity: 1,024 cubic feet

3. West 170th Street Tank

   Regulator: 6" Hydro-Brake
   Discharge rating: 1.25 CFS

   Capacity of Retention Tank: 2,074 cubic feet
   Volume of water stored: 1,900 cubic feet
   Excess capacity: 174 cubic feet

This completes the analysis of the methodology used by the City of Cleveland in computing the sizes and discharge ratings of the Hydro-Brakes which are currently in place within the referenced retention tanks. The figures and tables which are referenced in this section will now be presented.

TABLE D

Calculation of Drainage Areas

West 177th Street Tank

(Right-of-way set backs) + (Right-of-way) = Drainage Area

(50'+30'+30')1135' + (40'x290') = 136,450 $Ft.^2$

Drainage area = 3.1 Acres

Total area involved is 7.5 acres.

Puritas Avenue Tank

(Right-of-way set backs - W. 172) + (Right-of-way set backs - W. 170) +

(Right-of-way set backs - Puritas) + (Right-of-way - W. 172 & W. 170)

(40'+30'+30')518' + (40'+30'+30')222' + (80'+30'+30')504' + 40'(78'+78')

51,800 $Ft.^2$ + 22,200 $Ft.^2$ + 70,560 $Ft.^2$ + 6,240 $Ft.^2$

Drainage area = 150,800 $Ft.^2$

Drainage area = 3.5 acres

Total area involved is 7.9 acres.

West 170th Street Tank

(Right-of-way set backs - Martha Rd.) + (Right of way - W. 170)

(40' + 30')504' + (40' + 30' + 30')679'

35,280 $Ft.^2$ + 67,900 $Ft.^2$ = 103,180 $Ft.^2$

Drainage area = 2.4 acres

Total area involved is 5.7 acres.

TABLE E

Effect of Project on Storms of One Hour Duration

West 177th Street Tank

Frequency	6 Mo.	1 Yr.	3 Yr.	5 Yr.	10 Yr.
Depth	.66"	.90"	1.30"	1.50"	1.80"
Total Volume	7,500	10,200	14,800	17,000	20,400
Run-off Volume	3,750	5.100	7,400	8,500	10,000

Puritas Avenue Tank

Frequency	6 Mo.	1 Yr.	3 Yr.	5 Yr.	10 Yr.
Depth	.66"	.90"	1.30"	1.50"	1.80"
Total Volume	8,300	11,300	16,300	18,800	22,600
Run-off Volume	4,150	5,650	8,150	9,400	11,300

West 170th Street Tank

Frequency	6 Mo.	1 Yr.	3 Yr.	5 Yr.	10 Yr.
Depth	.66"	.90"	1.30"	1.50"	1.80"
Total Volume	5,600	7,700	11,100	12,900	15,500
Run-off Volume	2,800	3,850	5,500	6,450	7,750

Volumes are stated in cubic feet.

TABLE F

Effect of Project on 10 Year Storms of Various Durations

West 177th Street Tank

Duration	15 min.	30 min.	1 Hr.	2 Hr.	4 Hr.	6 Hr.
Depth	1.13"	1.55"	1.80"	2.10"	2.20"	2.30"
Total Volume	12,850	17,600	20,400	23,800	25,000	26,000
Run-off Volume	6,425	8,800	10,200	11,900	12,500	13,000

Puritas Avenue Tank

Duration	15 min.	30 min.	1 Hr.	2 Hr.	4 Hr.	6 Hr.
Depth	1.13"	1.55"	1.80"	2.10"	2.20"	2.30"
Total Volume	14,200	19,500	22,600	26,400	27,600	28,900
Run-off Volume	7,100	9,750	11,300	13,200	13,800	14,450

West 170th Street Tank

Duration	15 min.	30 min.	1 Hr.	2 Hr.	4 Hr.	6 Hr.
Depth	1.13"	1.55"	1.80"	2.10"	2.20"	2.30"
Total Volume	9,700	13,300	15,500	18,000	18,900	19,800
Run-off Volume	4,850	6,650	7,750	9,000	9,450	9,900

Volumes are stated in cubic feet.

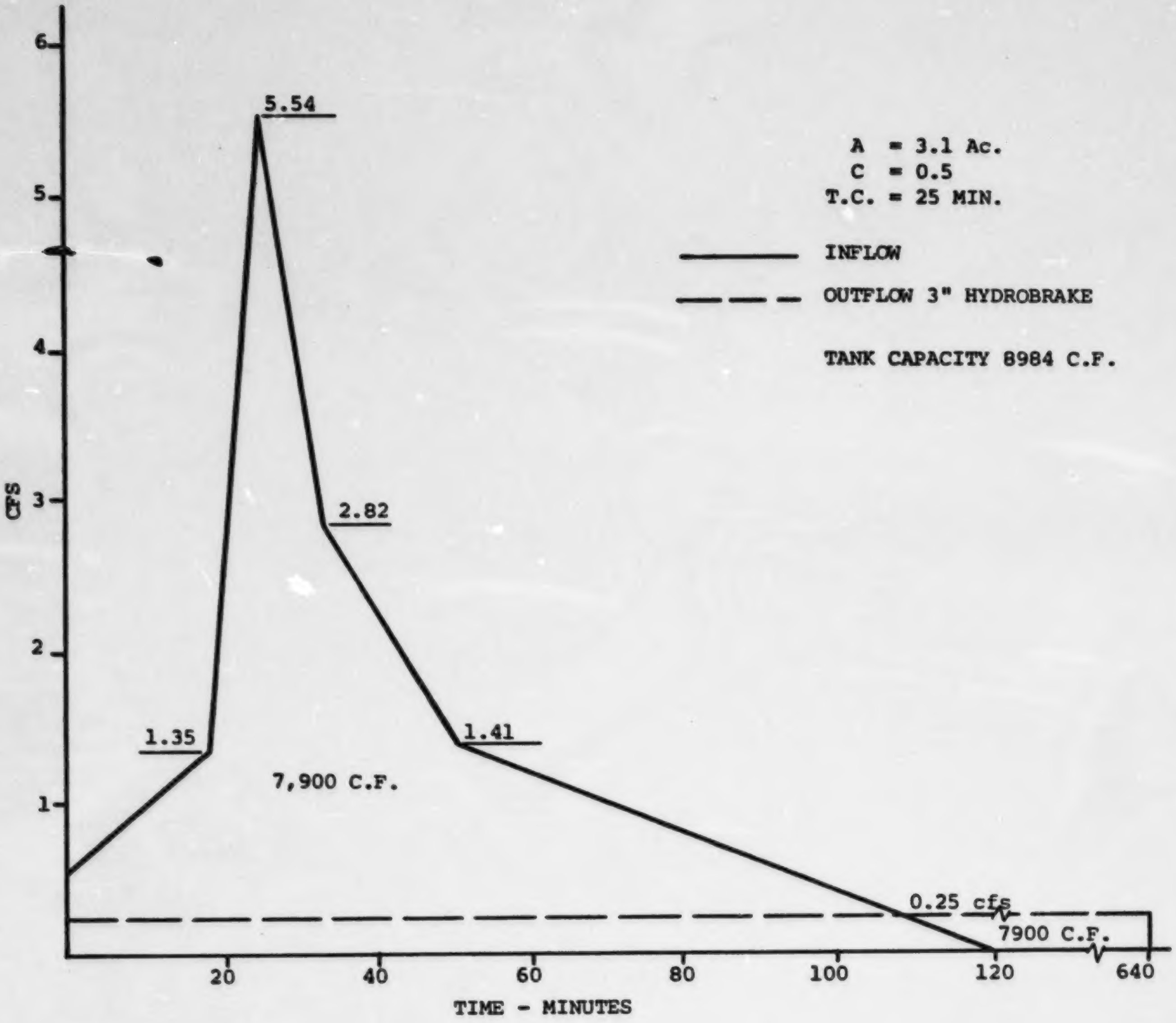

FIGURE 1 WEST 177 STREET TANK
HYDROGRAPH 10 YEAR STORM, 1 HR. DURATION

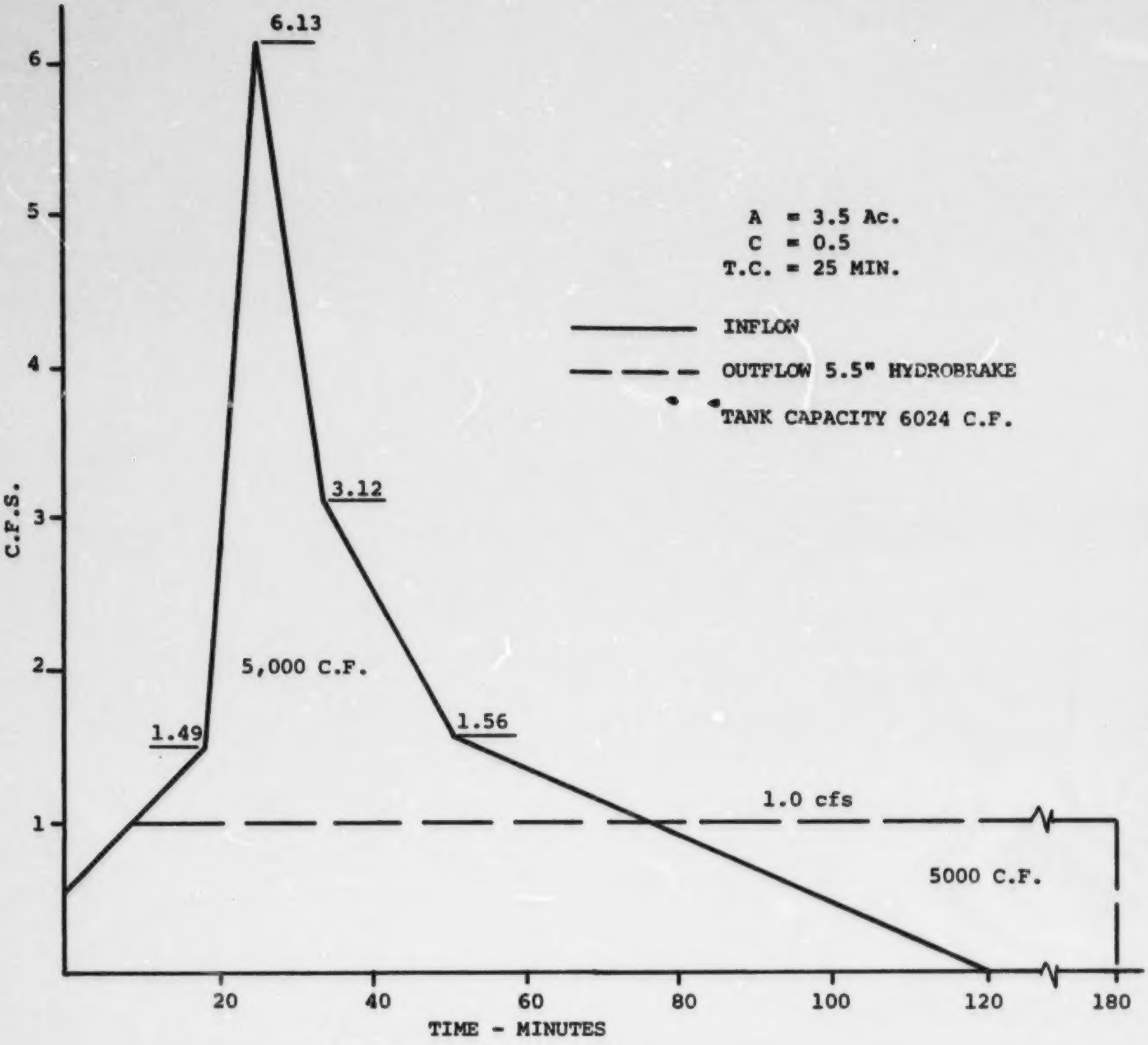

FIGURE 2 PURITAS AVENUE TANK
HYDROGRAPH 10 YEAR STORM, 1 HR. DURATION

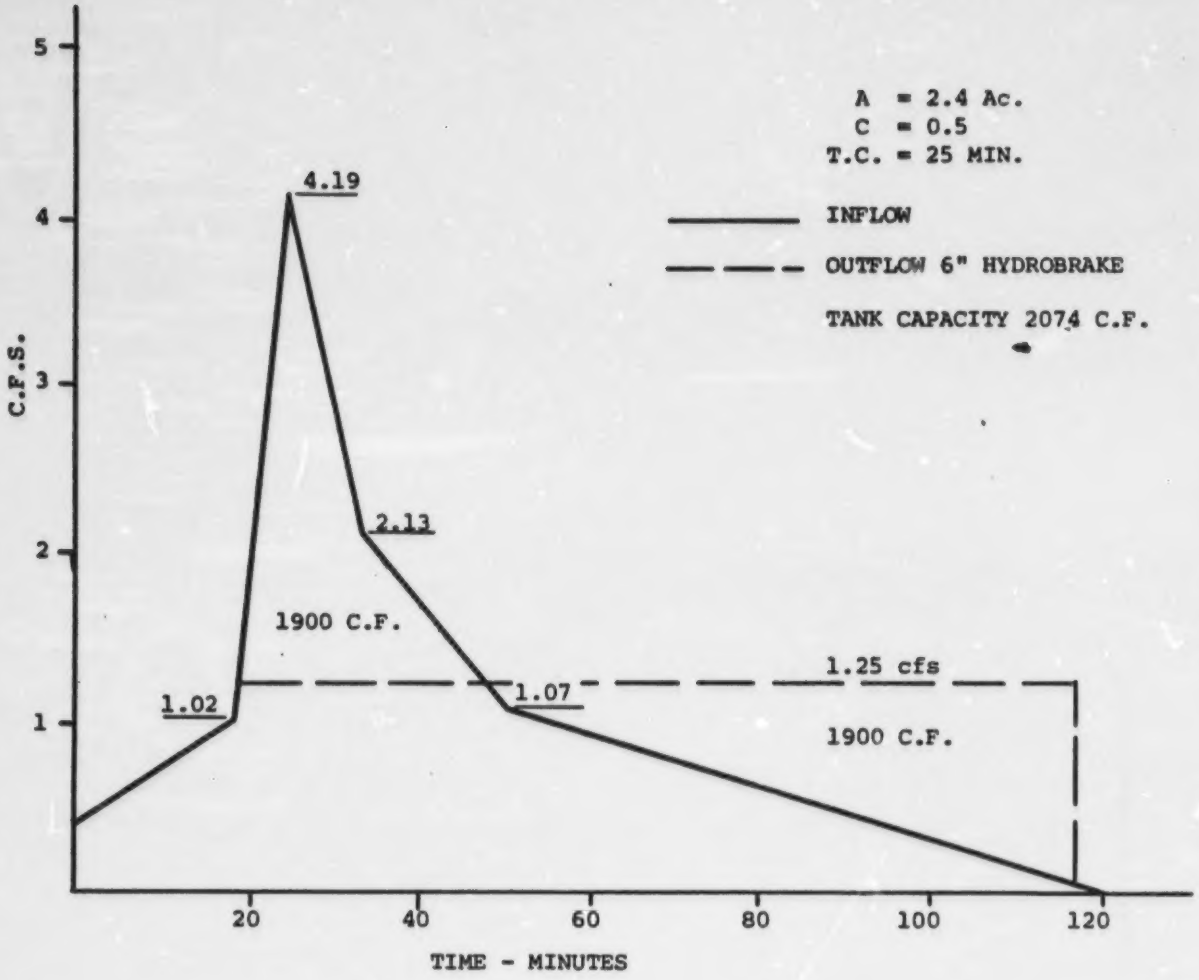

FIGURE 3 WEST 170 STREET TANK
HYDROGRAPH 10 YEAR STORM, 1 HR. DURATION

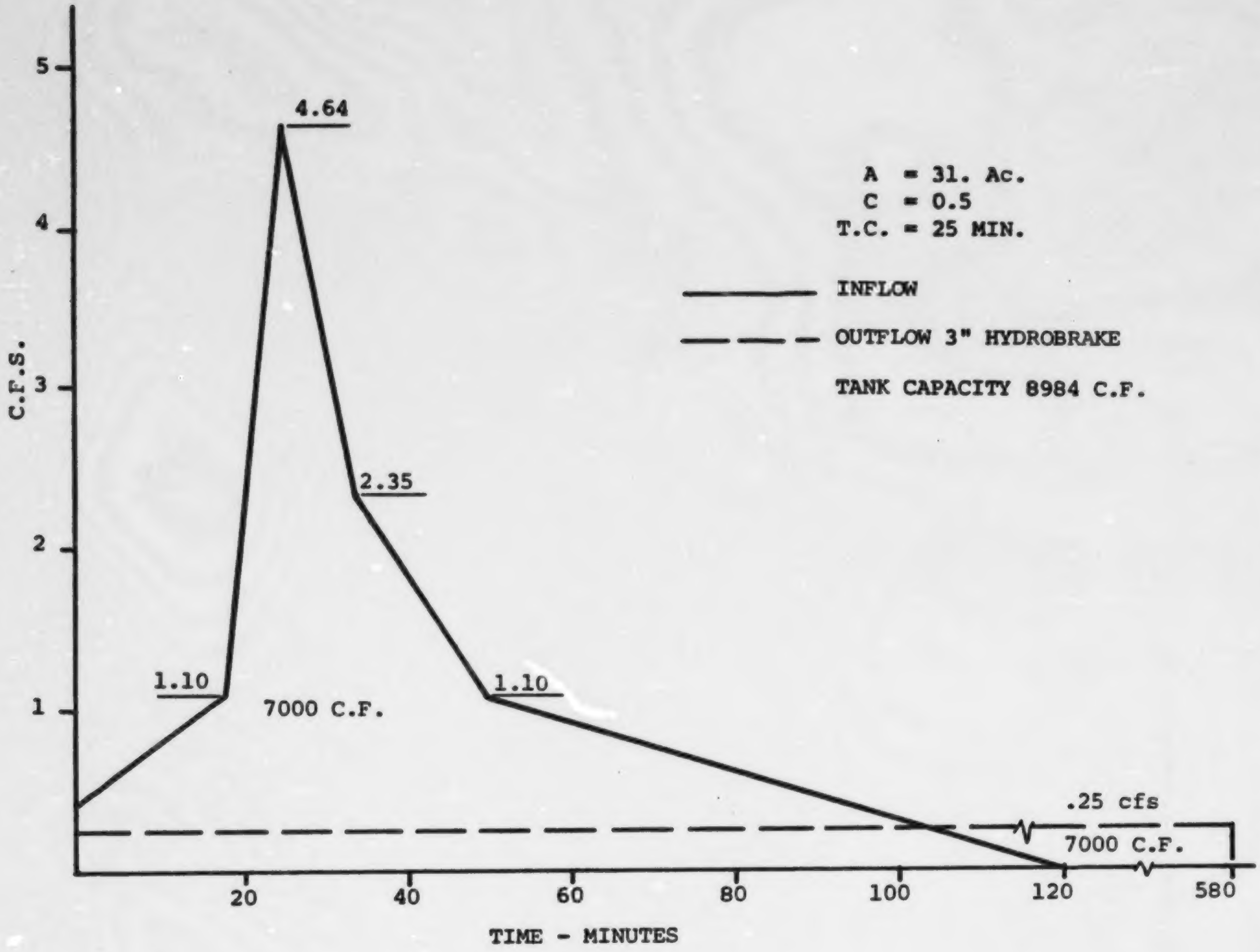

FIGURE 4 WEST 177 STREET TANK
HYDROGRAPH 5 YEAR STORM, 1 HR. DURATION

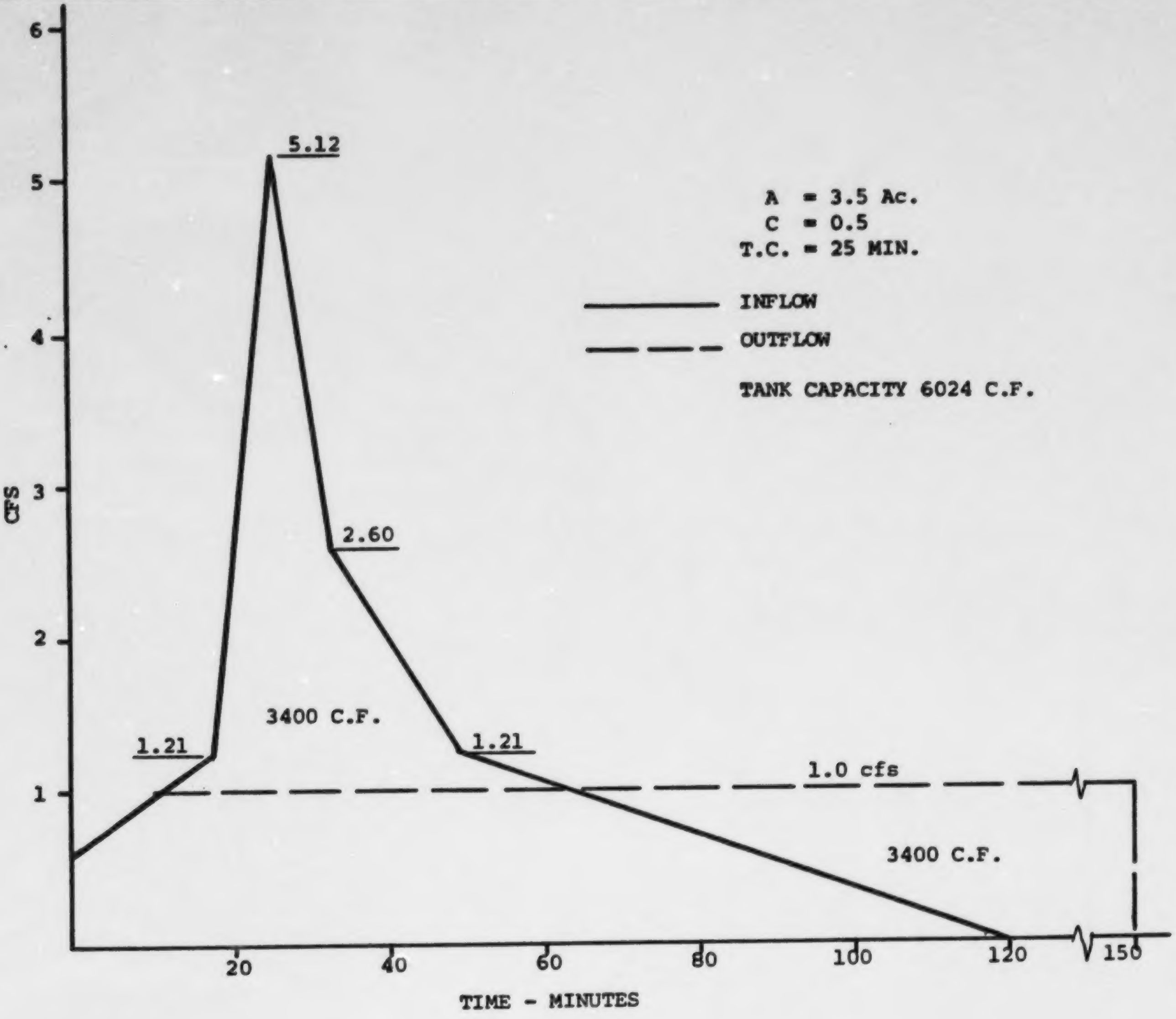

FIGURE 5 PURITAS AVENUE TANK
HYDROGRAPH 5 YEAR STORM, 1 HR. DURATION

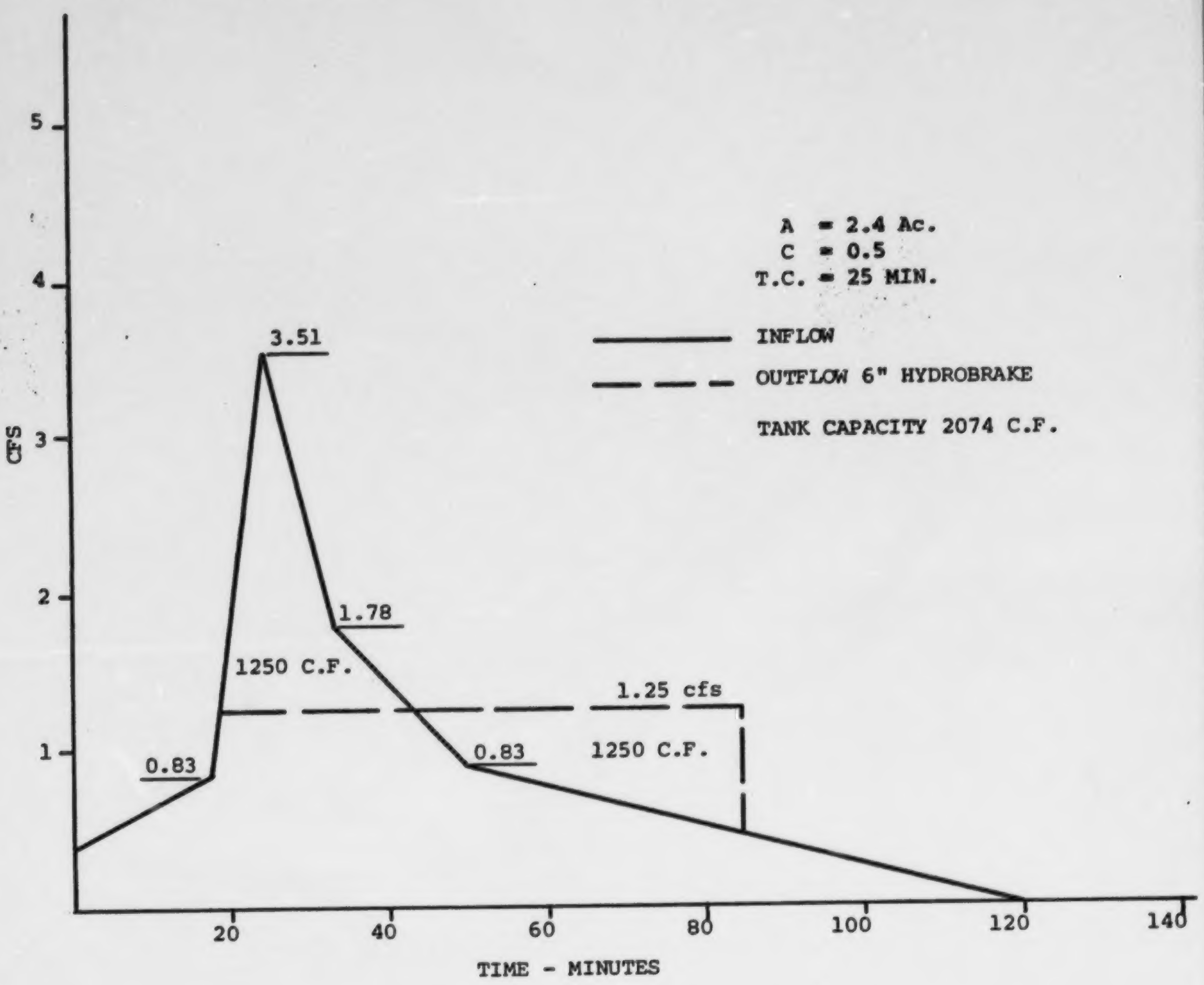

FIGURE 6 WEST 170 STREET TANK
HYDROGRAPH 5 YEAR STORM, 1 HR. DURATION

Guidelines For Design of Storm Water Retention Facilities

The third and final section of this appendix demonstrates the manner in which an interested party should proceed when designing Storm Water Retention Facilities which are similar in nature to those constructed under the auspices of the evaluated grant project. Our analysis will proceed by using one of the comparable projects which has previously been described within this appendix as an example. The manner in which this project, known as the Southwest Sewer Project - Phase II, was designed by the City of Cleveland will be considered in detail. It is hoped that from this description, other agencies which desire to implement this type of storm water control technology will be able to proceed with construction of their own facilities. It should be noted that additional, more detailed information concerning the design of these types of storm water retention facilities is available directly from the City of Cleveland's Department of Public Utilities, Division of Water Pollution Control.

The projects which were described within the preceding sections of this appendix were designed by the City of Cleveland for construction in areas of the City where both combined sewers are located and basement flooding problems are prevelant. The purpose of these projects was to provide the residences within the respective project areas protection from basement flooding up to the level of a five year storm of one hour duration.

Utilizing this design criteria, the following methodology was used by the City of Cleveland in designing the Southwest Sewer Project - Phase II.

1. The volume of storm flow which discharges directly into the existing combined sewer system from the house connections located within the project area was calculated using the Rational Method. The following methodology was used to make this calculation.

    a. The roof areas, and those yard areas (A) which drain into the house connections which are located within the project area, were estimated.

    b. Run-off Coefficients (C) for both the roof and yard areas within the project area were estimated.

    c. The time of concentration at the proposed discharge point, in this case a manhole, where the volume of flow can be checked for retention purposes, was estimated.

    d. Intensities (i) were obtained from rainfall intensity curves.

    e. The peak rate of flow was calculated using the Rational Method Equation. ($Q=CiA$)

2. The capacity of the existing sewer was calculated using Manning's Equation for calculating velocity of flow.

$$v= \frac{1.49}{N} \quad (R^{2/3} S^{1/2})$$

Q (capacity) = velocity x cross-sectional area of pipe = vA

3. A hydrograph at the subject manhole was constructed. The volume of flow which was used in constructing the referenced hydrograph included all storm run-off tributary to the referenced manhole.

4. The capacity of the existing sewer was compared with the peak flow of the house connections as calculated in step number one. Because the capacity of the existing sewer was greater than the peak flow, the peak flow was subtracted from the referenced capacity. The difference between these two figures was utilized for Hydro-Brake design.

The Construction of the Southwest Sewer Project - Phase II enabled the City of Cleveland to utilize Hydro-Brake Control Technology for two purposes.

A. To control the flow from the constructed retention tanks into the existing combined sewer system.

B. To control the flow from regulated catch basins into the existing combined sewer system. This was accomplished by the installation of small Hydro-Brakes in existing catch basins within the project area. These installations forced portions of the storm run-off within the area to bypass the regulated catch basins, which are connected to the existing combined sewer, and to flow directly into the catch basins which are connected to the constructed retention tank. The implementation of this technology also provided for additional storage of storm water run-off, as run-off is stored on the surface of the street, as well as within the constructed retention tanks.

In order to complete the storage tank design, a new hydrograph was constructed based upon existing hydrographs. This new hydrograph took into account the flow calculation computed in accordance with Step No. 1. The revised hydrograph also considered the amount of run-off which was to be routed into the proposed retention tanks and discharged through the Hydro-Brakes. It was determined that all volume not accounted for would be stored on the surface of the pavement.

Accordingly, the available surface storage areas were surveyed and the volume of storm water run-off which could be stored on the surface without causing serious street flooding problems was calculated. After this calculation had been made, the volume of required storage, as determined by the revised hydrograph, was computed. The volume of water to be stored on the surface was subtracted from the total storage required, thus yielding the volume of storm water to be stored within the retention tanks. These retention tanks are usually constructed and installed within a sidewalk or treelawn area.

As stated previously the Southwest Sewer Project - Phase II is to be utilized as an example of the demonstrated storm water control technology. Accordingly the reader's attention is drawn to the following calculations which were generated using the data available concerning the Bennington Avenue Area, a sub-section of what is now known as the Southwest Sewer Project - Phase II.

1. Calculation of storm flow which discharges directly into the Combined Sewer System.

Description	Area x Run-off Coefficient		Total (CA)
68 Homes	[68(25'x30')]x0.9	=	45,900 Sq. Ft.
34 Garages	[34(20'x10')]x0.9	=	6,120 Sq. Ft.
34 Yards	[34(20'x25')]x0.5	=	8,500 Sq. Ft.
			60,520 Sq. Ft.

Time of concentration t= 15 minutes
Intensity (5 yr. frequency) i=3.4 inches per hour

$$Q=CiA=60,520 \times 3.4$$

$$Q=CiA=205,768$$

Conversion to CFS $Q = \frac{205,768}{43,560} = 4.7$ CFS

2. Calculation of the capacity of the existing combined sewer system.

Size of pipe = 18" Vitrified Clay Pipe
Grade = .5 %
Roughness Coefficient, N = 0.015

Hydraulic Radius $R = \frac{\text{Area}}{\text{Perimeter}}$

$$R = \frac{1.77}{7.71} = 0.375$$

Velocity $v = \left(\frac{1.49}{N} \right)(R^{2/3} S^{1/2})$

$v = \left(\frac{1.49}{0.015} \right)(.375^{2/3} \times .005^{1/2})$

$v = 3.65$ FPS

Capacity $vA = (3.65)(1.77)$
$vA = 6.5$ CFS

3. The total volume of flow as determined by the revised hydrograph is 22,350 cubic feet.

Utilizing this information, it was determined that the retention tank to be constructed would be controlled with a 6 inch Hydro-Brake which possessed a discharge rating of 0.6 CFS. The determination was also made to regulate four additional catch basins which are located upstream away from the referenced retention tanks. Three regulated catch basins were modified by installing 4" Hydro-Brakes, with discharge ratings of .25 CFS.

With these modifications, the total discharge into the existing combined sewer system within the area was calculated as follows:

$$4.7 \text{ CFS} + 0.6 \text{ CFS} + (4 \times .25)\text{CFS} = 6.3 \text{ CFS}$$

This level of discharge is less than the maximum discharge rate of the system which was calculated previously. Thus, the design of the referenced retention tank was continued with the following calculations being generated.

1. Volume discharged into the system through the Hydro-Brakes.

$$V = 1.6 \times 70 \times 60 = 6{,}730 \text{ Cubic Feet.}$$

2. Volume discharged into the system through house connections.

$$V = \left(\frac{4.7 \times 55 \times 60}{2} \right) = 7{,}755 \text{ Cu. Ft.}$$

3. Total volume to be stored.

$$V = 22{,}350 - 6{,}730 - 7{,}755 = 7{,}865 \text{ Cubic Feet.}$$

4. Estimate of volume required to flood an area, 220' x 30', with an average depth of 6".

V = 220 x 30' x 0.5' = 3,300 Cubic Feet.

5. Total volume to be stored in retention facility.

V = 7,865 - 3,300 = 4,565 Cubic Feet.

In order to store the volume of water required, it was decided that 400 feet of reinforced concrete pipe, 48" in diameter, would be used. This yields the following available capacity for storage purposes.

V = 400 Lineal Ft. x 12.56 Cubic Ft. = 5,024 Cu. Ft.

The final calculation which needed to be made was the drain down time required to discharge the entire volume of storm flow.

Tank: 5,024 Cu. Ft. ÷ 0.6 = 8,373 seconds = 140 minutes
Street: 3,300 Cu. Ft. ÷ 0.6 = 5,500 seconds = 92 minutes

Total drainage time = 140 minutes + 92 minutes = 232 minutes.

This is equivalent to 3.9 hours.

CONCLUSION

This concludes Appendix F which has been authored by the City of Cleveland for the purpose of relating the experiences which it has had concerning the type of storm water control technology which has been evaluated during the course of this demonstration grant project. The City welcomes constructive comments from other interested parties who have had similar experiences related to this type of technology. These comments should be addressed as follows:

Commissioner, Division of Water Pollution Control
City of Cleveland
1825 Lakeside Avenue
Cleveland, Ohio 44114

Attention: Engineer of Sewer Design

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APPENDIX G

HYDRO BRAKE DEMONSTRATION PROJECT

SANTEE DRAINAGE AREA - ROCHESTER, NEW YORK

by

O'Brien & Gere Engineers, Inc.
Syracuse, New York 13221

6-1/2"
9-1/8"

February, 1982

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BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
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PAGE NUMBER
EPA Form 2350-4 (4-80)
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TYPING GUIDE SHEET

HYDRO-BRAKE DEMONSTRATION PROJECT
SANTEE DRAINAGE AREA - ROCHESTER, NEW YORK

GENERAL

The concept of inlet control to reduce downstream sewer system surcharging and resultant CSO discharges was demonstrated in the Santee Drainage Area in the City of Rochester, New York.

Past practices of removing stormwater runoff as quickly as possible have resulted in moving flooding and pollution problems downstream, potentially inducing more serious damage. By providing inlet control such that the rate of stormwater inflow does not exceed the capacity of the existing collection system, problems such as basement back-ups, shock loadings to downstream treatment facilities, and CSO discharges can be minimized or eliminated.

Inlet control practices by their nature, increase the frequency and extent of surface flooding. Surface flooding, however, is usually limited to short term ponding. In most instances this is preferable to the significant damage that may result from uncontrolled stormwater inflows.

One type of inlet control method recently introduced into the United States is a device known as the Hydro-Brake. This flow regulator was developed in Denmark and is marketed in North America by Hydro Storm Sewage Corporation. The Hydro-Brake is constructed of non-corrosive stainless steel, is self-regulating, contains no moving parts, and requires no power to operate. The movement of water through the Hydro-Brake involves a radial motion which dissipates energy to control the rate of discharge through an orifice. As the hydraulic head on the unit increases, the radial motion or angular velocity increases, thereby decreasing the coefficient of discharge through the orifice. At lower heads, the angular velocity decreases, thereby increasing the coefficient of discharge through the orifice. In this way, discharge through the orifice is kept relatively constant under a varying range of heads. A schematic of a Hydro-Brake regulator is presented in Figure 1.

An advantage of the Hydro-Brake unit, one that was investigated in this study, is that for a given sized orifice, an equally sized Hydro-Brake (diameter of Hydro-Brake orifice outlet = diameter of orifice) will discharge less flow at identical hydraulic heads.

PROJECT DESCRIPTION

This demonstration study consisted of two separate and independent investigations.

1. The concept of off-line storage detention with controlled release using a Hydro-Brake regulator. (Off-Line Storage Tank Study)

2. The concept of utilizing increased surface/street ponding of stormwater to reduce inflow to an existing combined sewer system. (Catchbasin Study)

Each concept offered a viable methodology to reduce the rate of inflow into the sewer system using flow restrictors. Such flow restrictors or regulators could be Hydro-Brakes, or specifically sized orifices used to throttle flow.

The demonstration study area is located on the west side of the City of Rochester and comprises 35 acres of primarily single family residential houses. The entire area is served by a combined sewer system which is tributary to the West Side Trunk Sewer. There are about 250 houses and 8 commercial establishments within the drainage area, many of which have roof leader connections to the combined sewer system. Sixty-two catchbasins within the area are presently connected directly to the

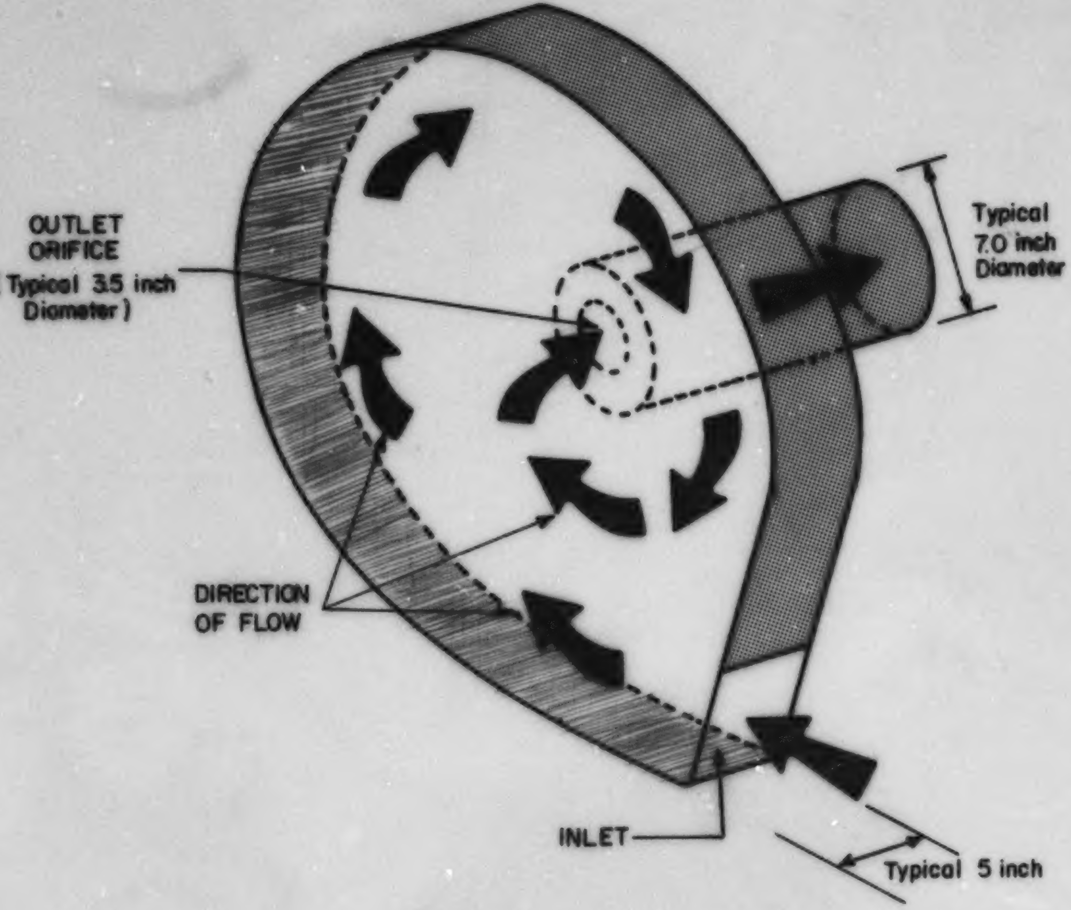
OUTLET ORIFICE (Typical 3.5 inch Diameter)
Typical 7.0 inch Diameter
DIRECTION OF FLOW
INLET
Typical 5 inch

Figure 1. Schematic of Hydro-Brake Regulator

combined sewer system. A schematic of the demonstration site is presented in Figure 2.

A field survey was conducted in the Santee Drainage Area to acquire necessary system information. The information obtained included sewer sizes and slopes, manhole inverts, the number and location of catchbasins, the number of house roof drain connections to the sewer system, and approximate street surface grades.

The Hydro-Brake units required for this study were ordered from Hydro Storm Sewage Corporation in December, 1980. After a series of unmet delivery dates, the Hydro-Brake units were finally received in late April, 1981. The Hydro-Brake designated for the off-line storage facility was installed within a week after delivery; however, modifications to the catchbasin Hydro-Brakes were required and installation of these units was not completed until June, 1981. These delays prevented the evaluation of early spring storms.

OFF-LINE STORAGE TANK STUDY

Background

The purpose of the off-line storage tank study was to evaluate the effectiveness of off-line storage in conjunction with Hydro-Brake regulated outflow, on the reduction of downstream sewer surcharge potential.

Using a reference storm with a return frequency of 2 years (60 minute duration, total rain = 0.75 inches, peak intensity = 1.5 in/hr), a plot of cumulative runoff volume vs. time was developed. This plot, shown in Figure 3, was used to determine a proper Hydro-Brake discharge rate and the capacity of the off-line storage tank. A Hydro-Brake discharge rate of 0.25 cfs at 50 inches of head, and an off-line storage tank capacity of 4700 gallons were selected. The original design of the off-line storage tank was subsequently modified, increasing the capacity of the tank to 5700 gallons.

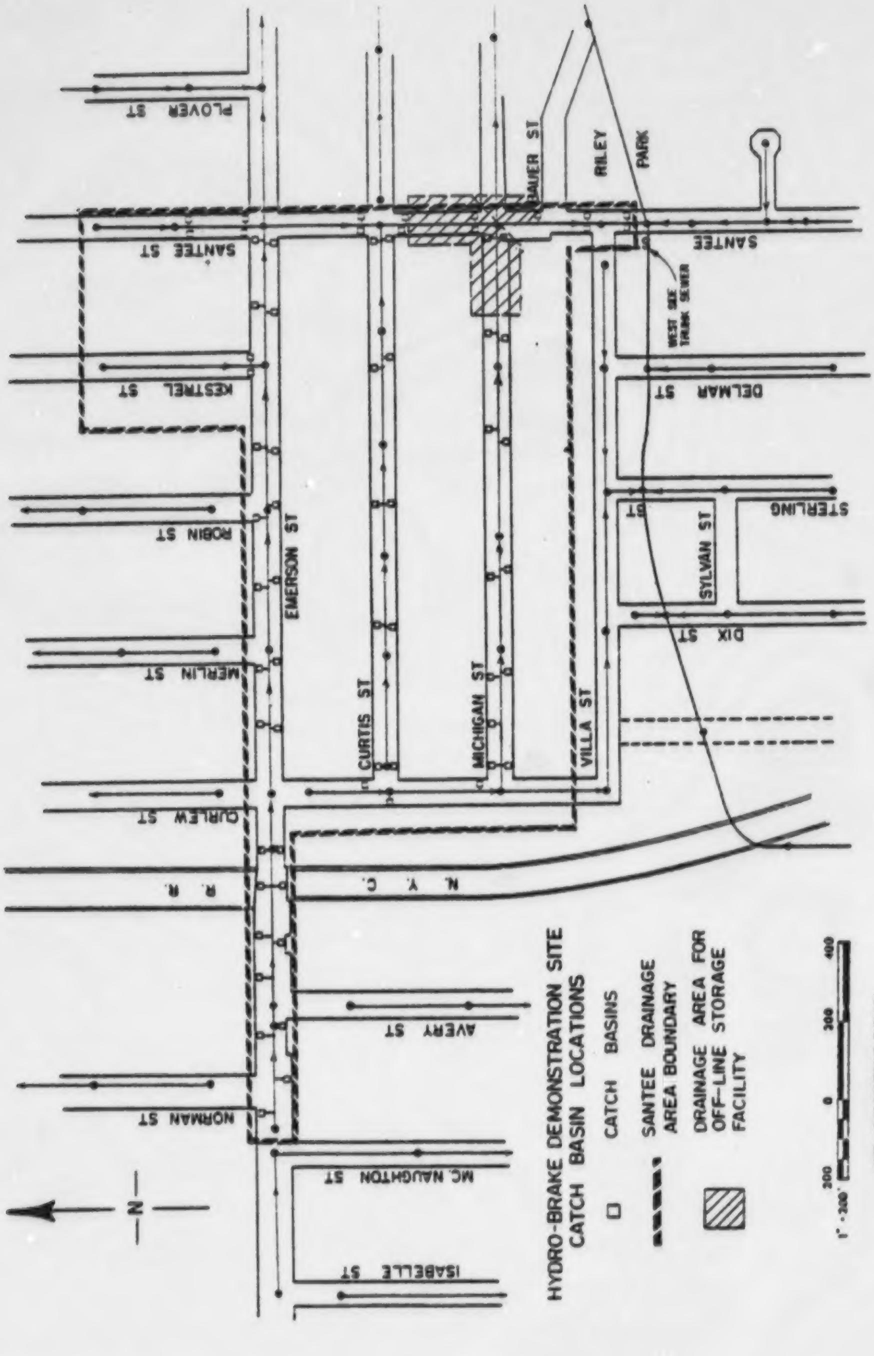
PLOVER ST
SANTEE ST
KESTREL ST
ROBIN ST
MERLIN ST
CURLEW ST
R. R.
N. Y. C.
AVERY ST
NORMAN ST
MC NAUGHTON ST
ISABELLE ST
EMERSON ST
CURTIS ST
MICHIGAN ST
VILLA ST
BAUER ST
RILEY
PARK
SANTEE
WEST SIDE TRUNK SEWER
DELMAR ST
STERLING
ST
SYLVAN ST
DIX ST
N
HYDRO-BRAKE DEMONSTRATION SITE
CATCH BASIN LOCATIONS
CATCH BASINS
SANTEE DRAINAGE AREA BOUNDARY
DRAINAGE AREA FOR OFF-LINE STORAGE FACILITY
1" = 200'
200
0
200
400
O'BRIEN & GERE ENGINEERS, INC

Figure 2. Schematic of Hydro-Brake Demonstration Site

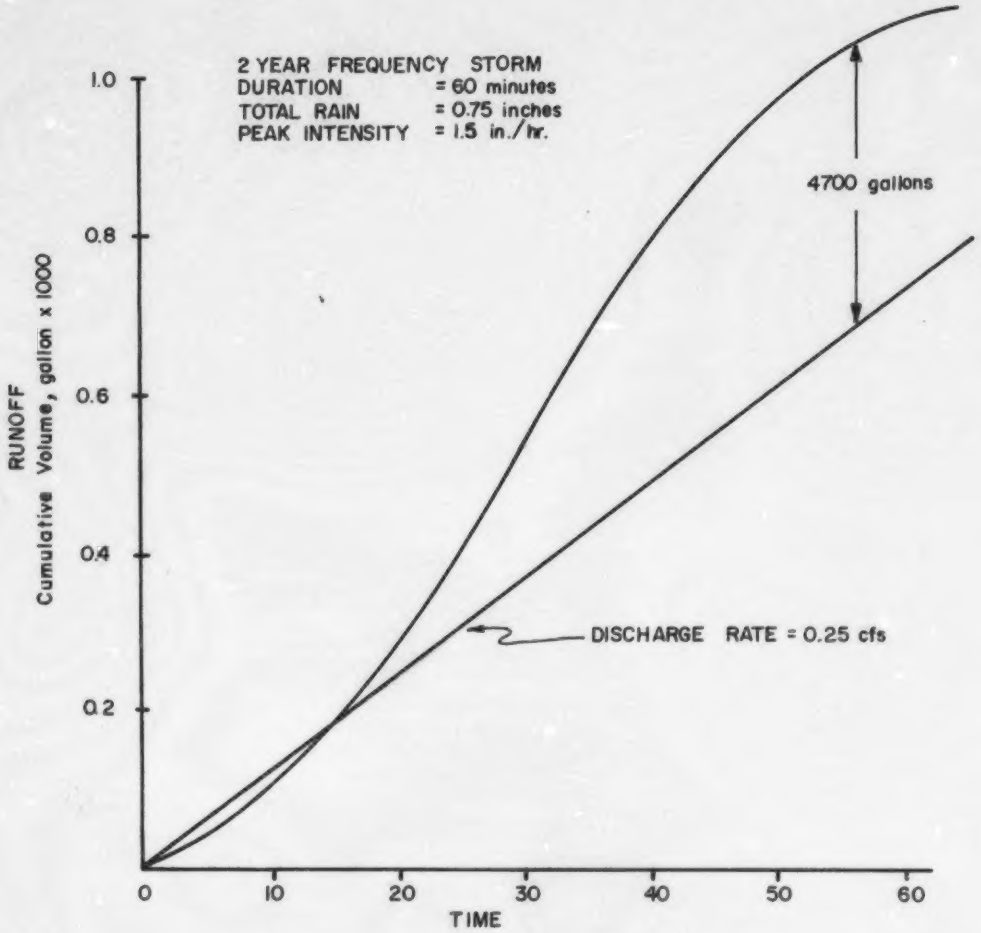

Figure 3. 2 Year Storm - Cumulative Runoff Volume vs. Time

The off-line storage tank was constructed using sections of 54-inch diameter reinforced concrete pipe. The pipe was laid end-to-end to create a tank 48 feet long. A manhole was installed at each end of the tank to provide access to facilitate maintenance and monitoring. The tank was sloped at 0.008 to allow for drainage.

Figure 4 presents a layout of the off-line storage facility area including the number and location of catchbasins tributary to the storage tank. In addition, the piping route connecting these catchbasins to the storage tank, and the route of the outlet pipe from the storage tank to the combined sewer system at Villa and Santee Streets, are shown in the figure. Discharge from the off-line storage tank is controlled by a Hydro-Brake (Standard 5-B-7) regulator, as shown in Figure 5. The Hydro-Brake regulator has a 3.5-inch diameter outlet orifice.

In order to restrict flow in the outlet pipe from the existing storage tank until the Hydro-Brake regulator was installed, a 3-inch diameter orifice, constructed from 0.75-inch plywood, was installed at the tank outlet. Figure 6 presents an overall plan and profile of the off-line storage facility.

Orifice Head-Discharge Tests

Prior to the installation of the Hydro-Brake, head-discharge tests were conducted on the orifice in the off-line storage tank. These tests led to the development of a head-discharge curve for the 3-inch orifice on the outlet pipe from the storage tank. The tests used to develop the head-discharge curve, are discussed below.

Variable Head Test --

The 6-inch diameter outlet pipe from the off-line storage tank was temporarily plugged at the manhole at Villa and Santee Streets. Using a nearby fire hydrant, the storage tank was filled. The temporary plug in the 6-inch outlet pipe was then removed and the level in the tank was

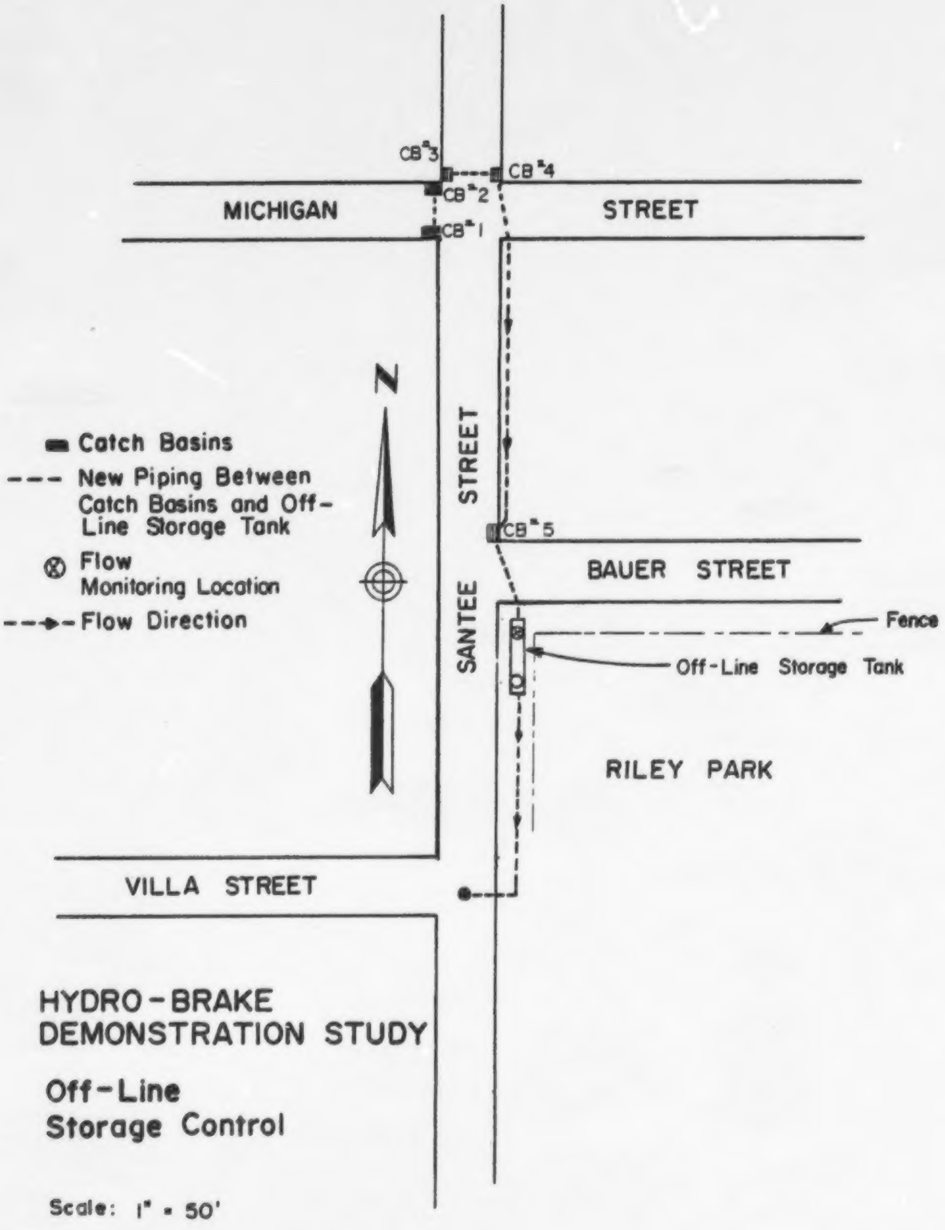
CB#3
CB#4
CB#2
CB#1
MICHIGAN
STREET
N
Catch Basins
New Piping Between Catch Basins and Off-Line Storage Tank
Flow Monitoring Location
Flow Direction
SANTEE STREET
CB#5
BAUER STREET
Fence
Off-Line Storage Tank
RILEY PARK
VILLA STREET
HYDRO-BRAKE DEMONSTRATION STUDY
Off-Line Storage Control
Scale: 1" = 50'

Figure 4. Schematic of Off-Line Storage Facilities Area

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best available copy.

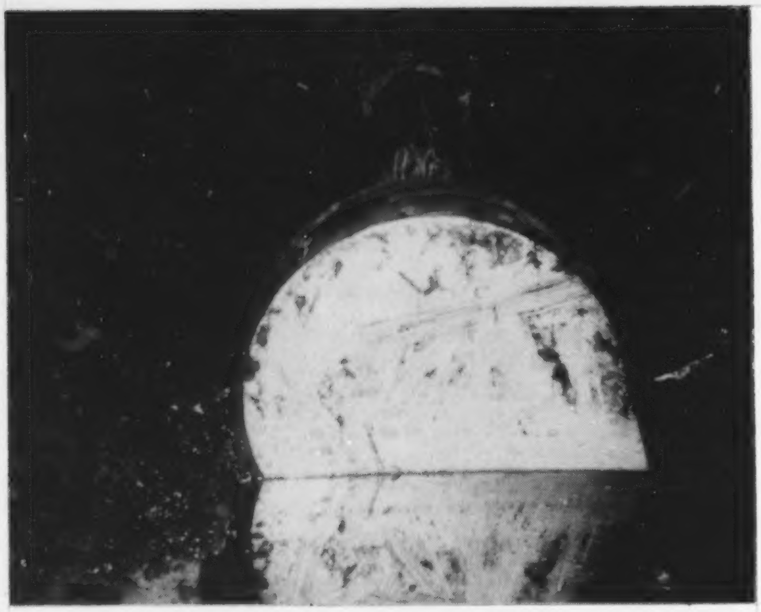


Figure 5. Hydro-Brake Regulator Installed in Off-Line Storage Tank

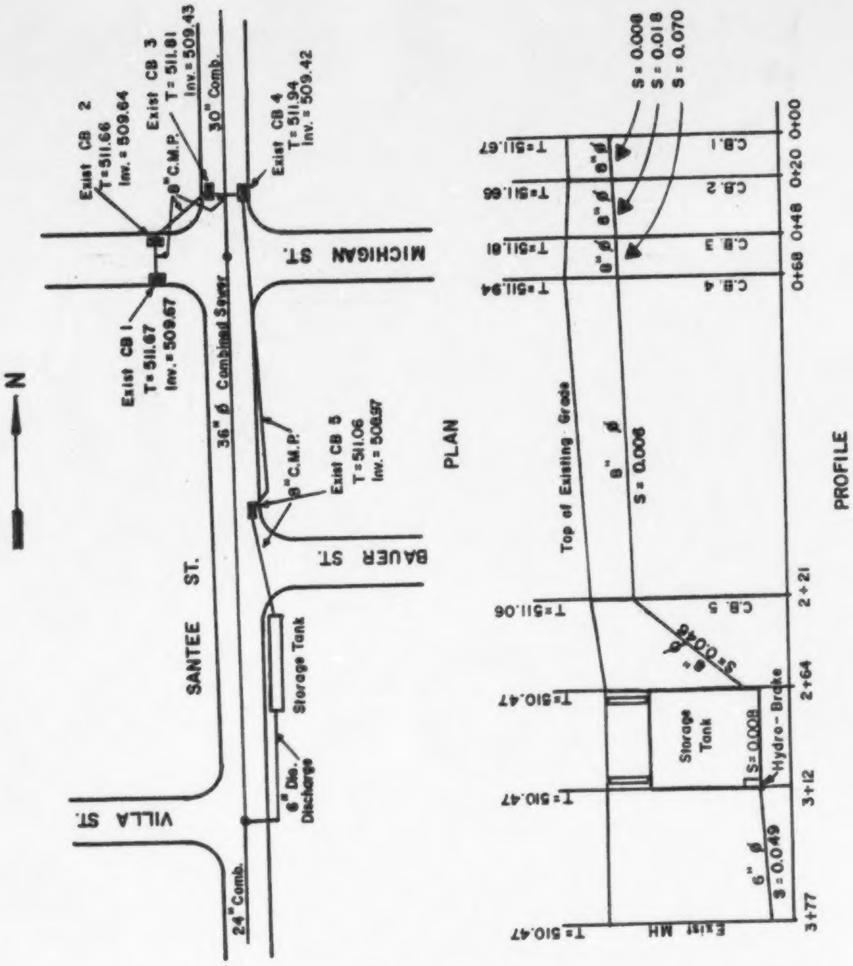

N
Exist CB 2
T=511.66
Inv.=509.64
Exist CB 3
T=511.81
Inv.=509.43
30" Comb.
8" C.M.P.
Exist CB 4
T=511.94
Inv.=509.42
MICHIGAN ST.
Exist CB 1
T=511.67
Inv.=509.67
36" ø Combined Sewer
8" C.M.P.
Exist CB 5
T=511.06
Inv.=508.97
PLAN
BAUER ST.
SANTEE ST.
Storage Tank
6" Dia. Discharge
VILLA ST.
24" Comb.
S=0.008
S=0.018
S=0.070
T=511.67
T=511.66
T=511.81
T=511.94
C.B.1
C.B.2
C.B.3
C.B.4
8" ø
0+00
0+20
0+48
0+68
Top of Existing Grade
8" ø
S=0.006
T=511.06
C.B.5
2+21
S=0.046
8" ø
T=510.47
Storage Tank
S=0.008
Hydro-Brake
2+64
T=510.47
3+12
6" ø
S=0.049
T=510.47
Exist MH
3+77
PROFILE

Figure 6. Plan & Profile of Off-Line Storage Tank Facilities

monitored at one minute intervals. The change in volume over each one minute interval (discharge) was plotted against the average head on the orifice during the one minute interval. The average head here was interpreted as the average between head at the beginning of the interval and head at the end of the interval. A curvilinear relation with a correlation coefficient equal to 0.94, was fitted to this data and is shown in Figure 7.

Static Head Test --

In this test, the depth in the off-line storage tank, and therefore the head on the orifice, was held constant at three different hydrant discharge rates. These three points were added to the plot of variable head test data for comparison. The three observations fit well into the expected variance about the curve developed for the variable head test, and therefore tended to confirm the results of that test.

Head-Discharge Curve --

The head and discharge data collected in the variable head test were transformed by taking their logarithms. A linear regression function was then fitted to the plot of Log h vs. Log Q; where h = Head, Q = Discharge. The resulting equation was:

$$\text{Log } Q = -0.6135 + 0.5394 \text{ Log } h$$

By taking antilogs of this equation, the following expression is obtained:

$$Q = 0.2435\ h^{0.5394}$$

The standard equation for discharge through an orifice is:

$$Q = CA\ \sqrt{2gh}$$

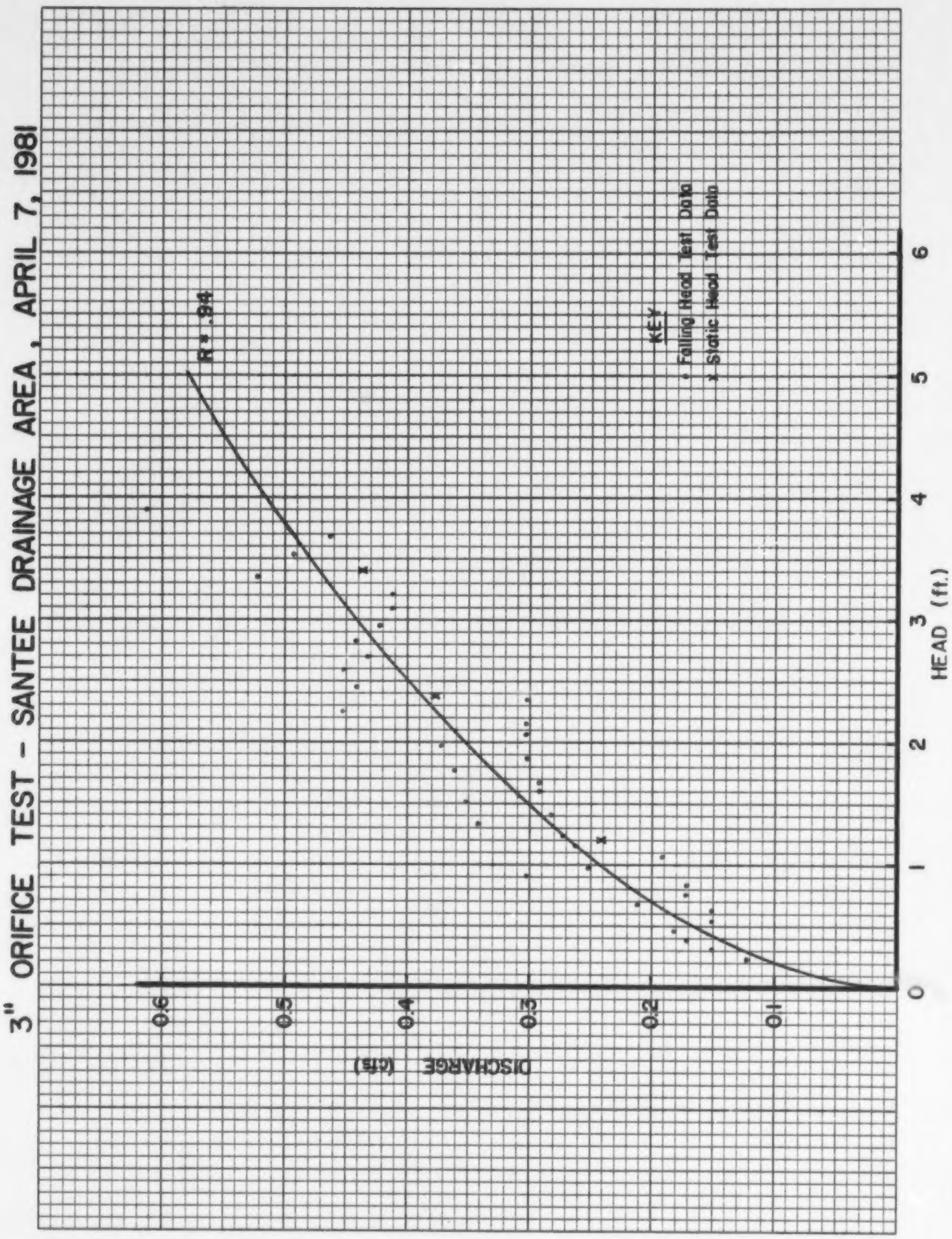


Figure 7. Discharge Curve - 3-Inch Orifice Test

where Q = Discharge
A = Area of orifice
g = Acceleration of gravity
h = Head on orifice
C = Coefficient of discharge

A comparison between the two equations can be made.

Test Data Equation (Q)		Standard Orifice Equation (Q)
$0.2435\ h^{0.5394}$	$\simeq$	$CA\sqrt{2gh}$
$0.2435\ h^{0.5394}$	$\simeq$	$CA\sqrt{2g}\ h^{0.5000}$

In the standard equation, h is raised to the 0.5000 power. The equation obtained from the variable head test data shows h raised to the 0.5349 power, consistent (within experimental error) with the value in the standard equation. To solve for C, the coefficient of discharge, h is factored from the equation.

$$0.2435 \simeq CA\sqrt{2g}$$

For this test data, $C \simeq 0.62$, which is consistent with most reported values of $C \simeq 0.60$. As a result of this observation, the test procedures described above were considered to be appropriate in the evaluation of discharge from the off-line storage tank.

Hydro-Brake Head-Discharge Tests

Head-discharge tests were conducted on a Hydro-Brake Standard 5-B-7 unit installed in the off-line storage tank in the Santee Drainage Area. These tests led to the development of a head-discharge curve for this Hydro-Brake. The tests used to develop this curve were the same as those used to develop the head-discharge curve for the 3-inch orifice. Data from these tests (variable head and static head) are presented in

Figure 8. A curvilinear relation with a correlation coefficient equal to 0.80, was fitted to the variable head test data. Again, the three observations taken in the static head test fit well within the expected variance about this curve.

Head-Discharge Curve --

As for the orifice, head and discharge data collected in the variable head test were transformed by taking logarithms. A linear regression function was then fitted to the plot of Log h vs. Log Q; where h = Head, Q = Discharge. The resulting equation was:

$$\text{Log } Q = -0.7897 + 0.3290 \text{ Log } h$$

By taking antilogs, the following equation was obtained:

$$Q = 0.1623\, h^{0.3290}$$

In a general comparison with the orifice equation, in which discharge is dependent on head to the 0.5000 power, it is seen that discharge from the Hydro-Brake depends on head raised to the 0.3290 power. This indicates that compared to an orifice, the Hydro-Brake will tend to dampen discharges associated with higher heads. The curve, fit to the variable head test data in Figure 8, shows this effect.

Hydro Storm Head-Discharge Curve --

Figure 9 shows the head-discharge relationship for a Hydro-Brake (Standard 5-B-7),with a 3.5-inch outlet orifice, as defined by data supplied by Hydro Storm Sewage Corporation. The curve developed from the Hydro-Brake testing at the off-line storage tank is presented for comparison.

Generally the relationship provided by Hydro Storm slightly underestimates discharge at given heads. This is not considered to be a

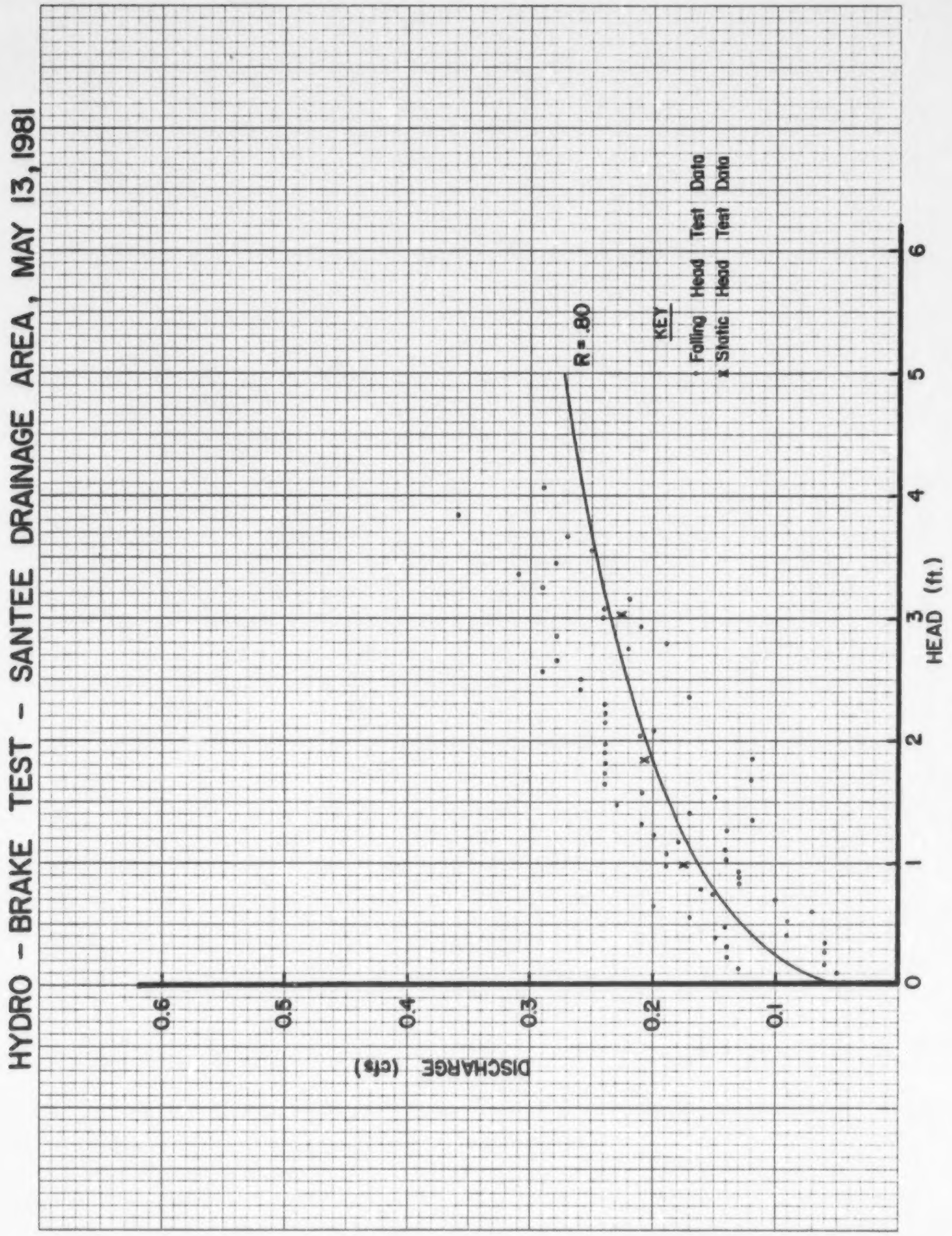


Figure 8. Discharge Curve - Hydro-Brake Test

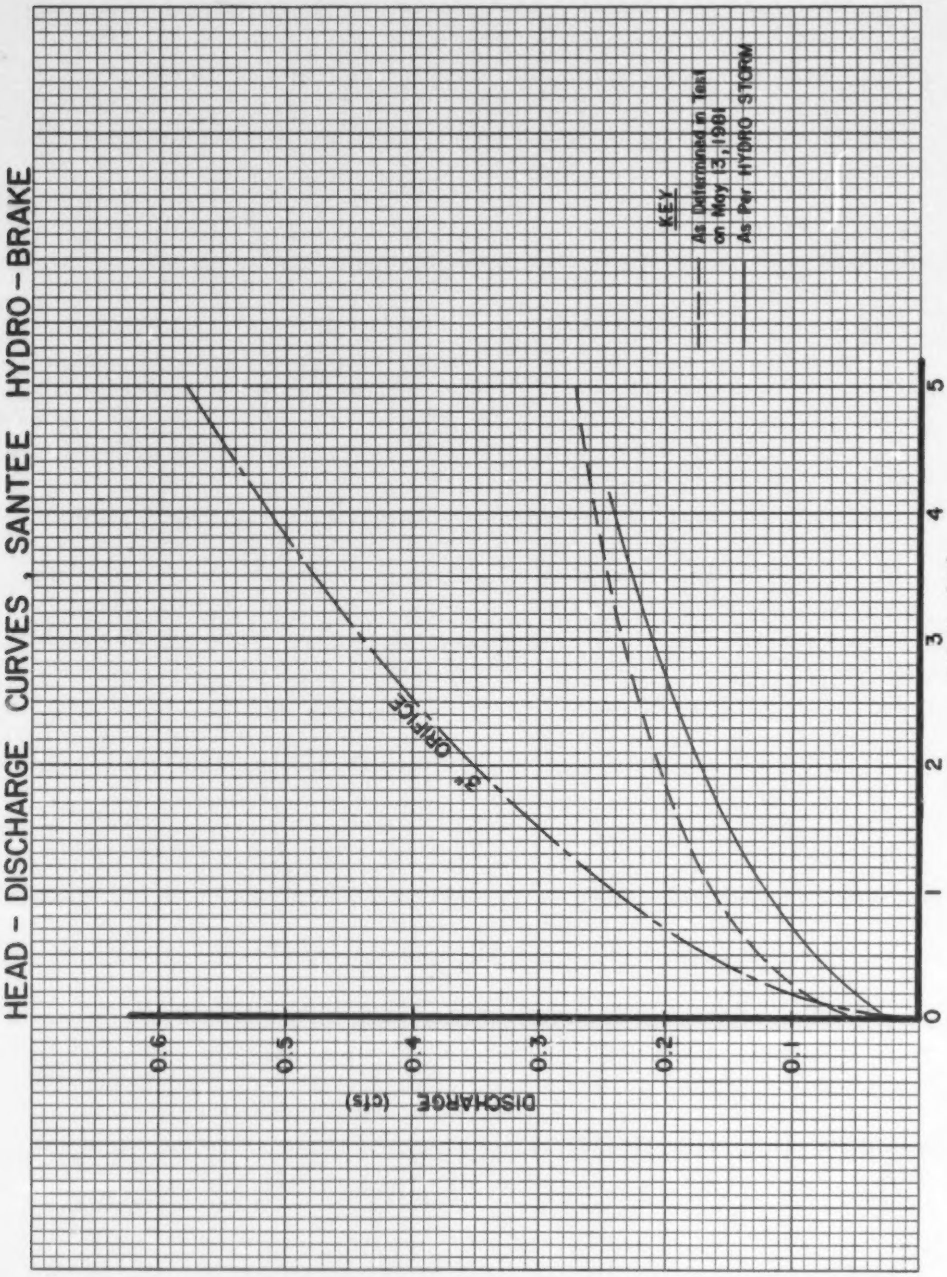


Figure 9· Discharge Curves - Hydro-Brake Demonstration Project serious discrepancy as differences between the developed and Hydro Storm curves can be attributed to experimental and roundoff errors, as well as minor variations in the manufacturing process.

Storm Monitoring Results

Fifteen storms were monitored during the period from May 11 to August 11, 1981 at the off-line storage tank in the Santee Drainage Area. On August 5th, additional discharge tests were conducted on the Hydro-Brake regulator. These tests resulted in the development of a discharge curve that was strikingly similar to a discharge curve for a 3.5-inch orifice. Upon further investigation at the site, a 15-inch long piece of lath was found lodged inside the Hydro-Brake. The lath was found positioned in a manner that would have prevented flow from developing a radial motion within the Hydro-Brake. The development of this radial motion is necessary in order to dissipate energy in the flow and reduce the coefficient of discharge through the Hydro-Brake's 3.5-inch outlet orifice.

On September 4th, subsequent to the removal of the piece of lath, further tests were conducted on the Hydro-Brake regulator. The discharge curve developed as a result of these tests compared well with the initial discharge curve, shown in Figure 8, developed in May.

Four of the fifteen monitored storms at the off-line storage tank occurred in August, during the period of time that the Hydro-Brake was determined to have been rendered ineffective due to the lodged piece of lath. Of the remaining eleven storms, five filled the storage tank to at least 20% of its maximum depth. These five storms were considered significant, and the impacts of these storms were analyzed in more detail.

On the evening of May 11, 1981 over a one hour-45 minute period, 0.37 inches of rainfall was recorded at the Rochester-Monroe County Airport. Runoff from this storm was monitored at the off-line storage tank. Using the developed head-discharge curve for the Hydro-Brake in the storage tank, inflow (uncontrolled) and outflow (Hydro-Brake controlled) hydrographs were developed. These hydrographs are shown in Figure 10.

The inflow hydrograph was developed using the equation:

$$I = E + \frac{\Delta s}{\Delta t}$$

where I = inflow

E = outflow

$\frac{\Delta s}{\Delta t}$ = change in storage tank volume with respect to change in time.

Values of outflow (E) were obtained from the Hydro-Brake head-discharge curve using average values of head on the Hydro-Brake. Values of $\frac{\Delta s}{\Delta t}$ were developed from monitoring data at the storage tank.

During each interval, average head was interpreted as the average between head at the beginning of the interval and head at the end of the interval.

The hydrographs presented in Figure 10 show that peak discharges to the combined sewer system are reduced by the Hydro-Brake installed in the off-line storage tank. The peak discharge rate of 1.038 cfs, representing the peak uncontrolled discharge to the sewers, was reduced by 75%. The peak discharge rate through the Hydro-Brake was observed to be 0.260 cfs. Total volume discharged to the sewers in the first 50 minutes of this storm (that portion of the storm where inflow to the tank exceeded outflow) was reduced by 60%.

Storms on June 4th, July 2nd, July 9th, and July 20th were analyzed in the same manner as discussed above. The results of these analyses are summarized in Table 1. Figures 11-14 show the inflow (uncontrolled) and outflow (Hydro-Brake controlled) hydrographs for each of these storms.

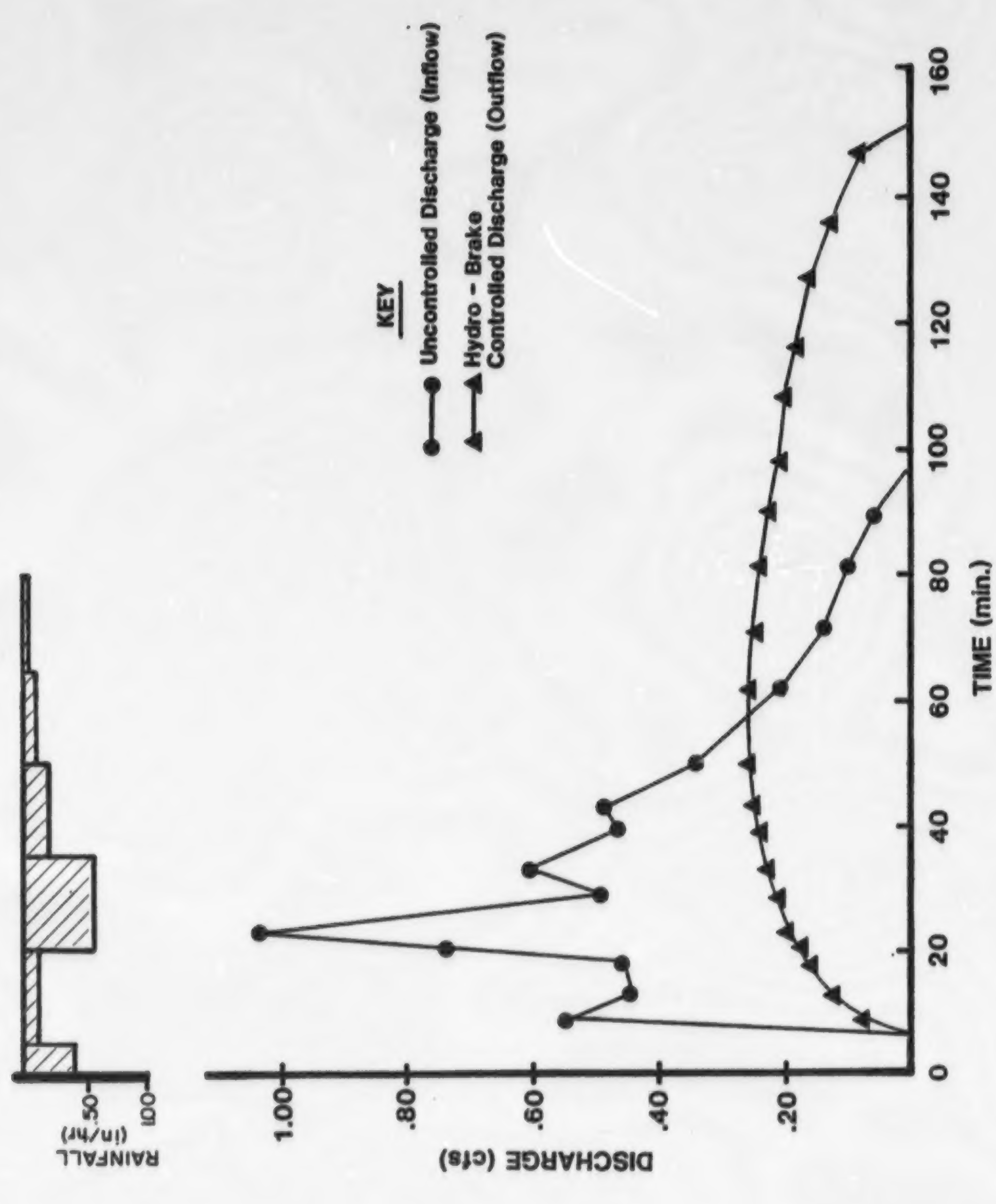


Figure 10. Storm of May 11, 1981 - Santee Drainage Area

TABLE 1. STORM MONITORING RESULTS AT OFF-LINE STORAGE TANK

Date	Total Rain* (Inches)	Peak Uncontrolled Discharge (cfs)	Peak Hydro-Brake Discharge (cfs)	% Reduction	Total Uncontrolled Discharge (gallons)	Total Hydro-Brake Discharge (gallons)	Total Hydro-Brake Discharge / Total Uncontrolled Discharge (%)
5-11-81	0.37	1.038	0.260	75.0	13,616	12,716	93.4
6-04-81	0.04	0.331	0.146	55.9	2,658	2,366	89.0
7-02-81	0.52	0.996	0.213	78.6	4,865	5,296	108.9
7-09-81	0.21	0.536	0.186	65.3	3,947	3,937	99.7
7-20-81	1.27	0.327	0.180	45.0	6,061	5,990	98.8

*As recorded at the Rochester-Monroe County Airport.

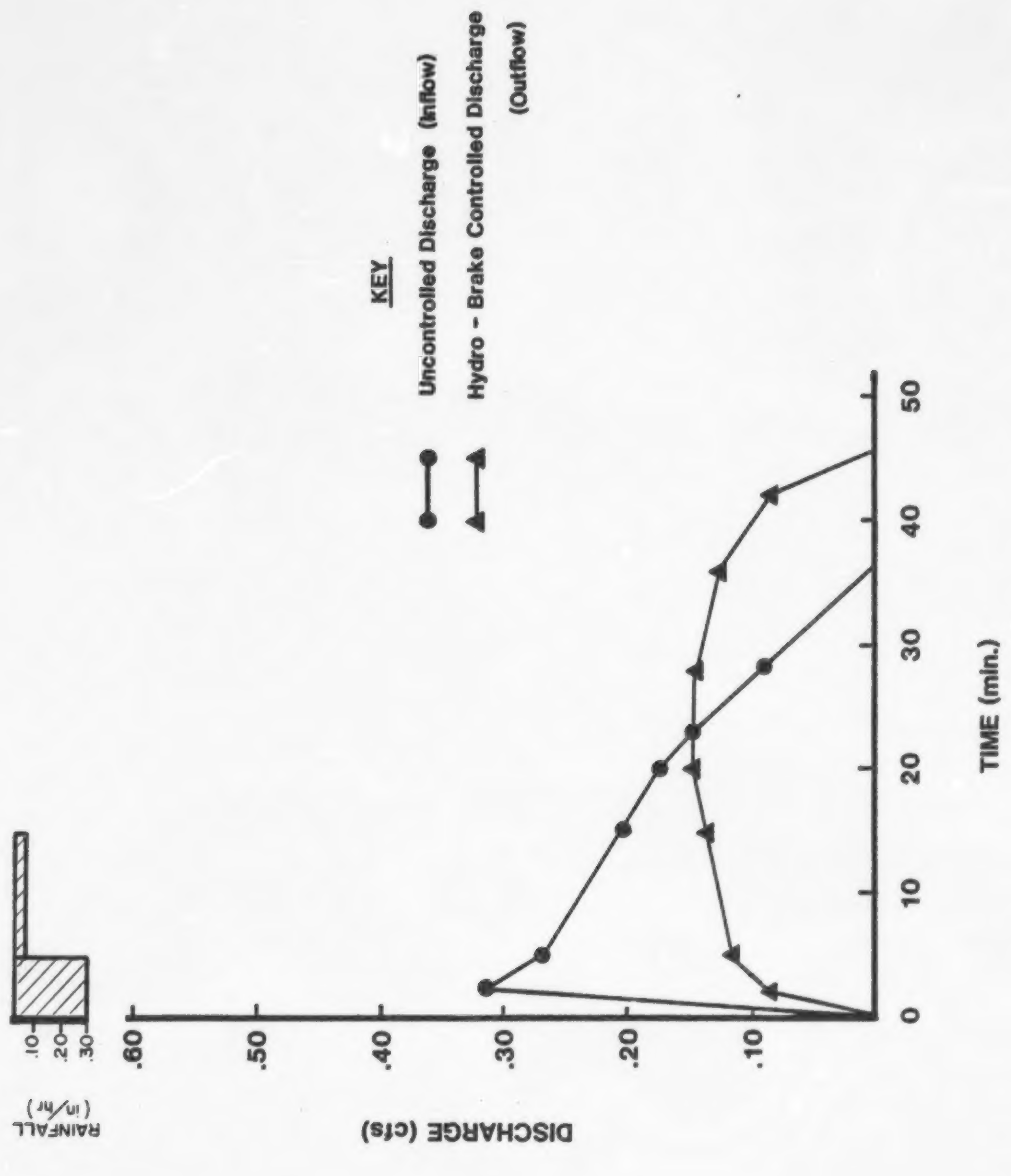


Figure 11. Storm of June 4, 1981 - Santee Drainage Area

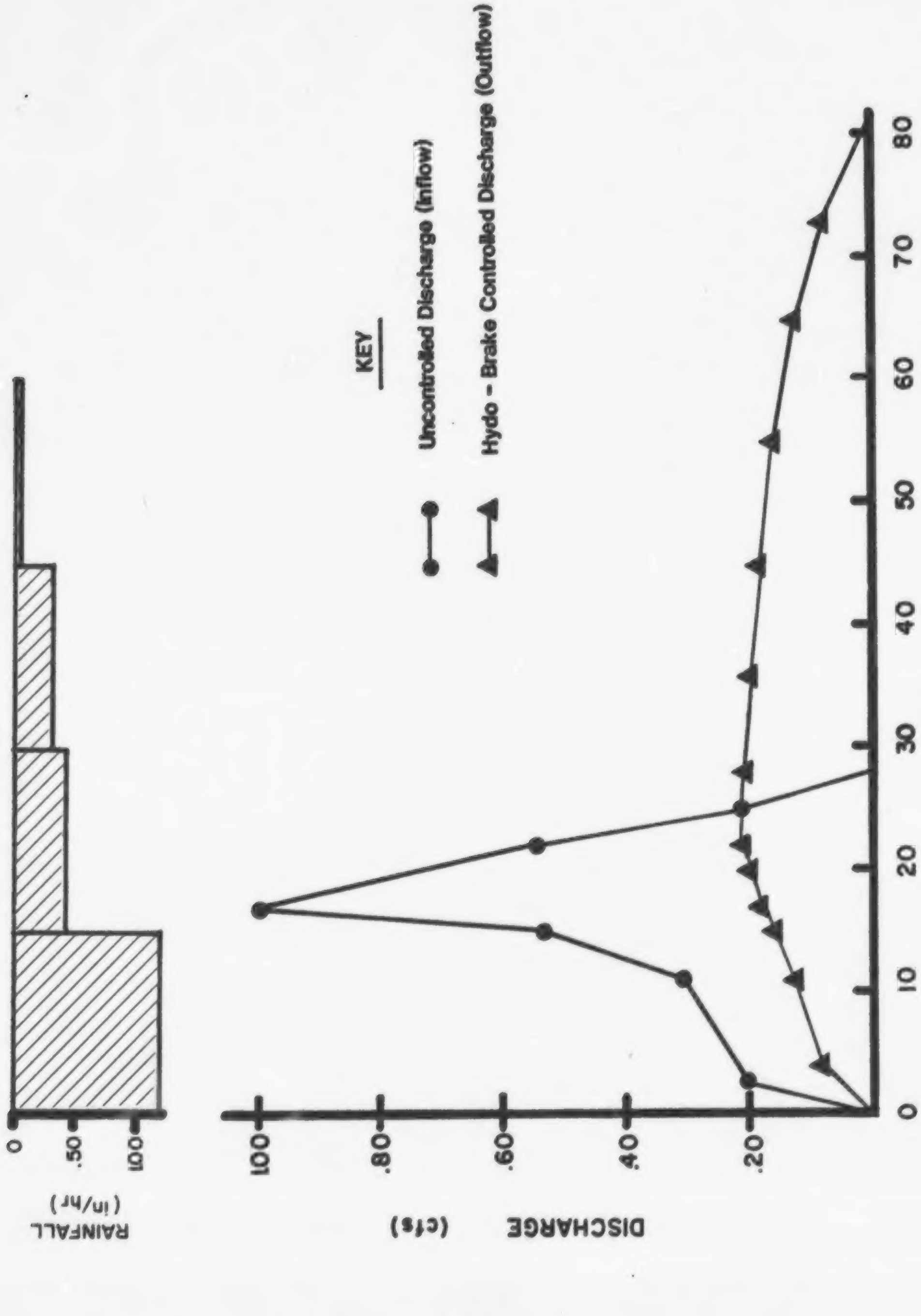


Figure 12. Storm of July 2, 1981 - Santee Drainage Area

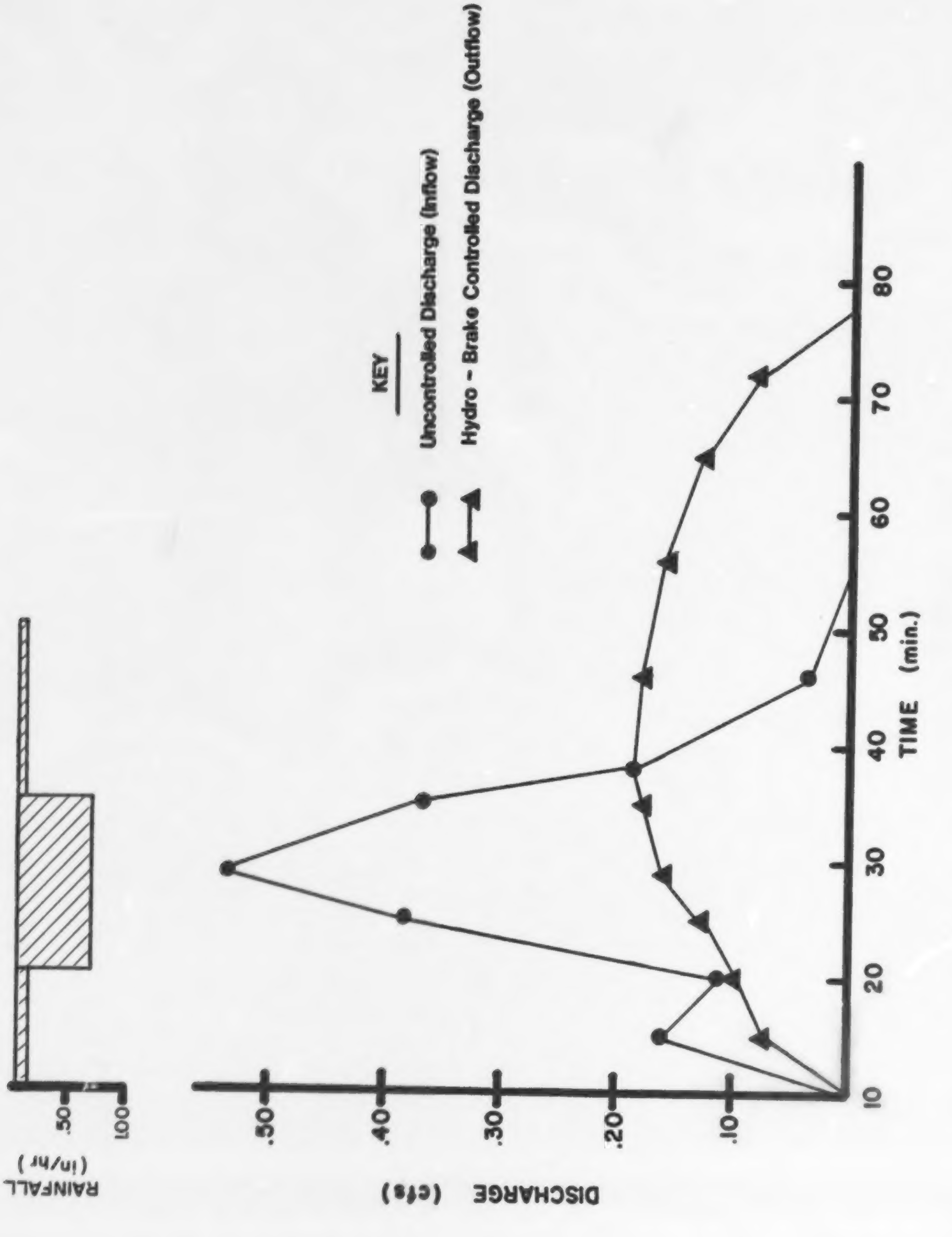


Figure 13. Storm of July 9, 1981 - Santee Drainage Area

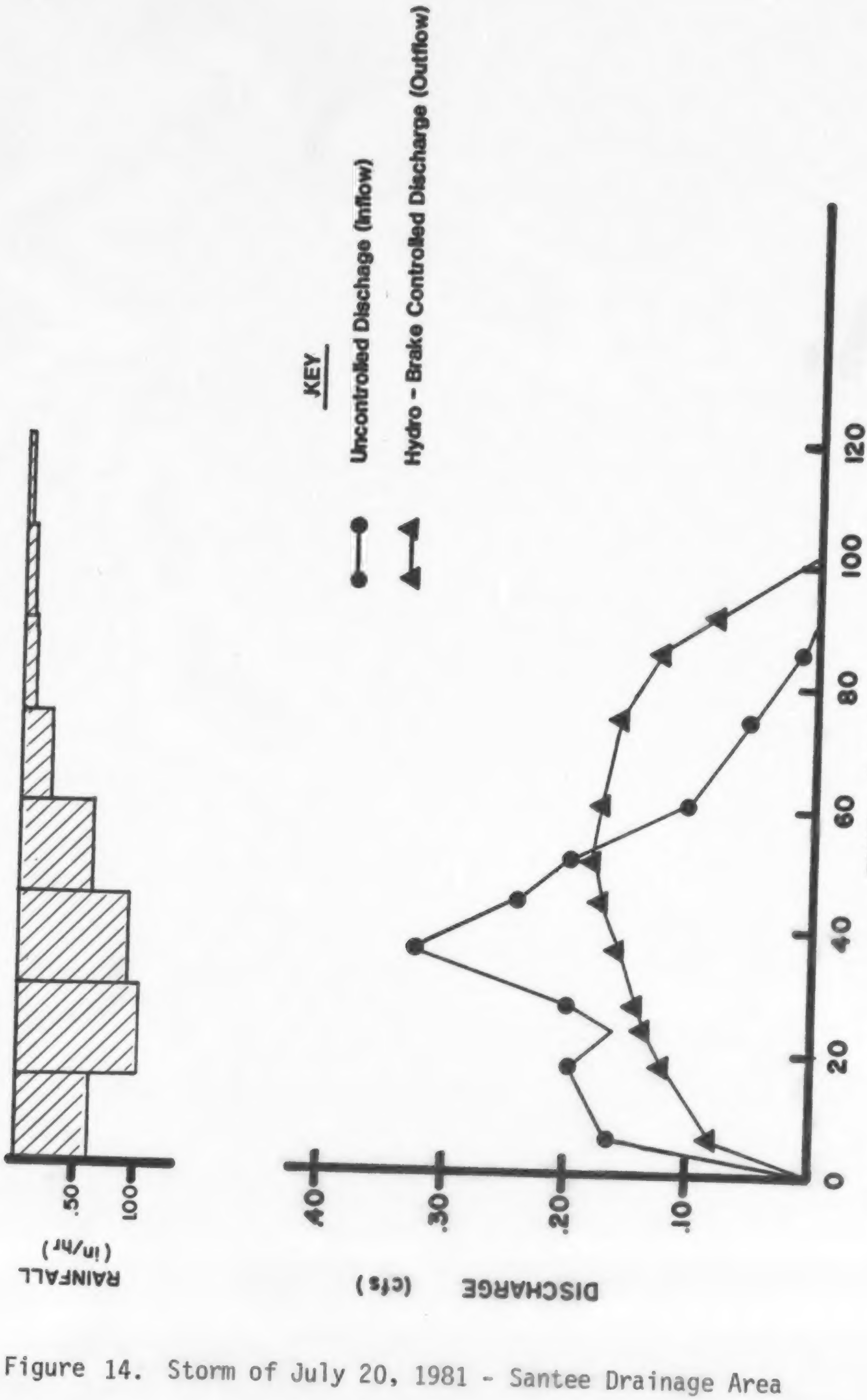


Figure 14. Storm of July 20, 1981 - Santee Drainage Area

As in the storm on May 11, peak discharge rates from these storms were substantially reduced by the Hydro-Brake regulator. The percent reductions ranged from 78% on July 2, to 45% on July 20.

Relatively little correlation can be seen between total rain and peak discharges. This is probably due, at least in part, to the 4-mile distance between the rain gage at the Rochester-Monroe County Airport and the Santee Drainage Area.

Discrepancies between the total uncontrolled discharges and the total Hydro-Brake discharges are due primarily to experimental and roundoff errors.

Operation and Maintenance

The maintenance required at the off-line storage tank was minimal. Over the four month demonstration period (May-August), only 2-3 inches of fine debris built up at the lower end of the tank. Although these depositions did not affect the normal operation of the Hydro-Brake unit, a larger piece of stromwater debris did become lodged in the Hydro-Brake, temporarily rendering the unit ineffective. Upon removal of the debris, operation of the Hydro-Brake returned to normal. Given the nature of stormwater debris, it may be good practice to check the Hydro-Brake after every major storm to ensure its normal operation.

Installation Costs

The following represent the construction costs incurred installing the off-line storage facility described above:

	Total	Costs Attributable to Storage Tank	Costs Attributable to Collection System
Labor	$ 7,450	$4,800	$ 2,650
Storage Tank	2,320	2,320	
Piping	5,250		5,250
Equipment Rental (Dump Truck, Crane, Operator)	2,450	1,500	950
Materials (Gravel, Ready-Mix Concrete, Stone)	2,065	500	1,565
Restoration (Binder, Top Asphalt, Topsoil)	855	150	705
1 - Hydro-Brake Unit (5-B-7)	525	525	
	$20,915	$9,795	$11,120 (ENR = 3510)

The costs of this alternative method to reduce the rate of inflow into an existing collection system, are comparable with costs of other off-line storage alternatives as outlined in the 1978 Needs Survey: Cost Methodology for Control of Combined Sewer Overflow and Stormwater Discharges (NTIS PB-296 604). The costs of this alternative, about $1.72 per gallon of storage, compare favorably with the $2.05 per gallon of storage figure taken from the 1978 Needs Survey (ENR = 3510).

CATCHBASIN STUDY

Background

The purpose of the catchbasin study was to evaluate the effectiveness of reduced inflow rates to the combined sewer system on the frequency of surcharge conditions. A reduction of inflow rates was accomplished by sealing a number of selected catchbasins in the Santee Drainage Area. Hydro-Brake regulators were then installed in the remaining catchbasins in the drainage area. This combination allowed for limited surface/street ponding of stormwater, thereby reducing the rate of runoff into the combined sewer system.

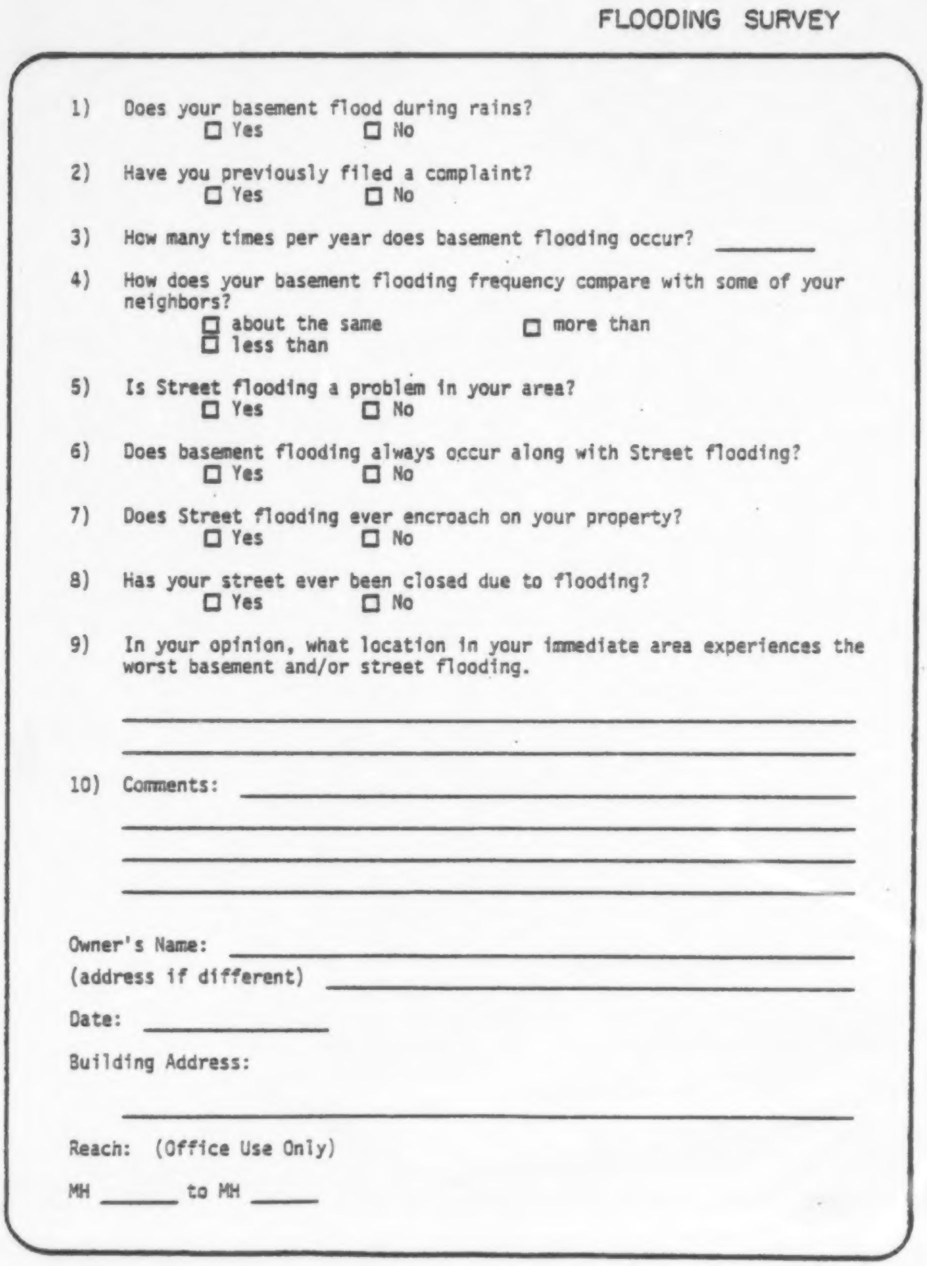
Homeowner Survey

A complaint analysis was conducted to identify the existing flooding problems within the study area. Information was obtained through distribution of a homeowner survey, as shown in Figure 15, and review of previous complaint records filed with Monroe County. About 25 percent of the total number of surveys (241), which were hand distributed to homeowners in the study area, were returned. Table 2 presents the street location, number of responses, and the number of responses which indicated basement flooding problems.

TABLE 2. SANTEE HOMEOWNER SURVEY RESULTS*

Street	No. of Responses Received	No. of Responses w/Basement Flooding
Michigan	14	6
Curtis	16	2
Emerson	14	3
Kestrel	3	0
Curlew	3	0
Santee	6	0

*Based on a 25% survey response.



FLOODING SURVEY

1) Does your basement flood during rains?
☐ Yes ☐ No

2) Have you previously filed a complaint?
☐ Yes ☐ No

3) How many times per year does basement flooding occur? ________

4) How does your basement flooding frequency compare with some of your neighbors?
☐ about the same ☐ more than
☐ less than

5) Is Street flooding a problem in your area?
☐ Yes ☐ No

6) Does basement flooding always occur along with Street flooding?
☐ Yes ☐ No

7) Does Street flooding ever encroach on your property?
☐ Yes ☐ No

8) Has your street ever been closed due to flooding?
☐ Yes ☐ No

9) In your opinion, what location in your immediate area experiences the worst basement and/or street flooding.

10) Comments:

Owner's Name:
(address if different)
Date:
Building Address:

Reach: (Office Use Only)
MH ______ to MH ______

Figure 15. Homeowner Survey Questionnaire

A review of the Monroe County complaint records indicated several occurrences of basement flooding in the Santee Drainage Area over the last three years. The complaint records, however, were so brief that it was difficult to determine the impact that surcharging of the combined sewer system may have had on basement flooding.

Study Description

In order to determine the extent of sewer surcharging conditions prior to the sealing and installation of Hydro-Brakes in selected catchbasins, sewer flows in the study area were monitored. Monitoring was accomplished using level sensing equipment at five locations within the drainage area. Monitoring equipment used in this study consisted of Manning Level Recorders (L-3000A), and NB Electronic Manhole Meters (GS). The flow monitoring locations are listed below and are shown in Figure 16.

- Emerson and Robin
- Curtiss and Santee
- Curtiss - 2 MH west of Santee
- Michigan - 2 MH west of Santee
- Villa and Santee

Storm flows at these locations were monitored in 1980, prior to the sealing of any catchbasins or the installation of Hydro-Brakes.

Preliminary stormwater modeling of the sewer system in the Santee Drainage Area was conducted to help determine the number and location of catchbasins to be fitted with Hydro-Brake regulators. A field survey of street surface grades was also conducted in order to locate areas of natural depression that would facilitate stormwater ponding. The results of this survey and the preliminary stormwater modeling indicated the need for Hydro-Brakes at 11 catchbasin locations.

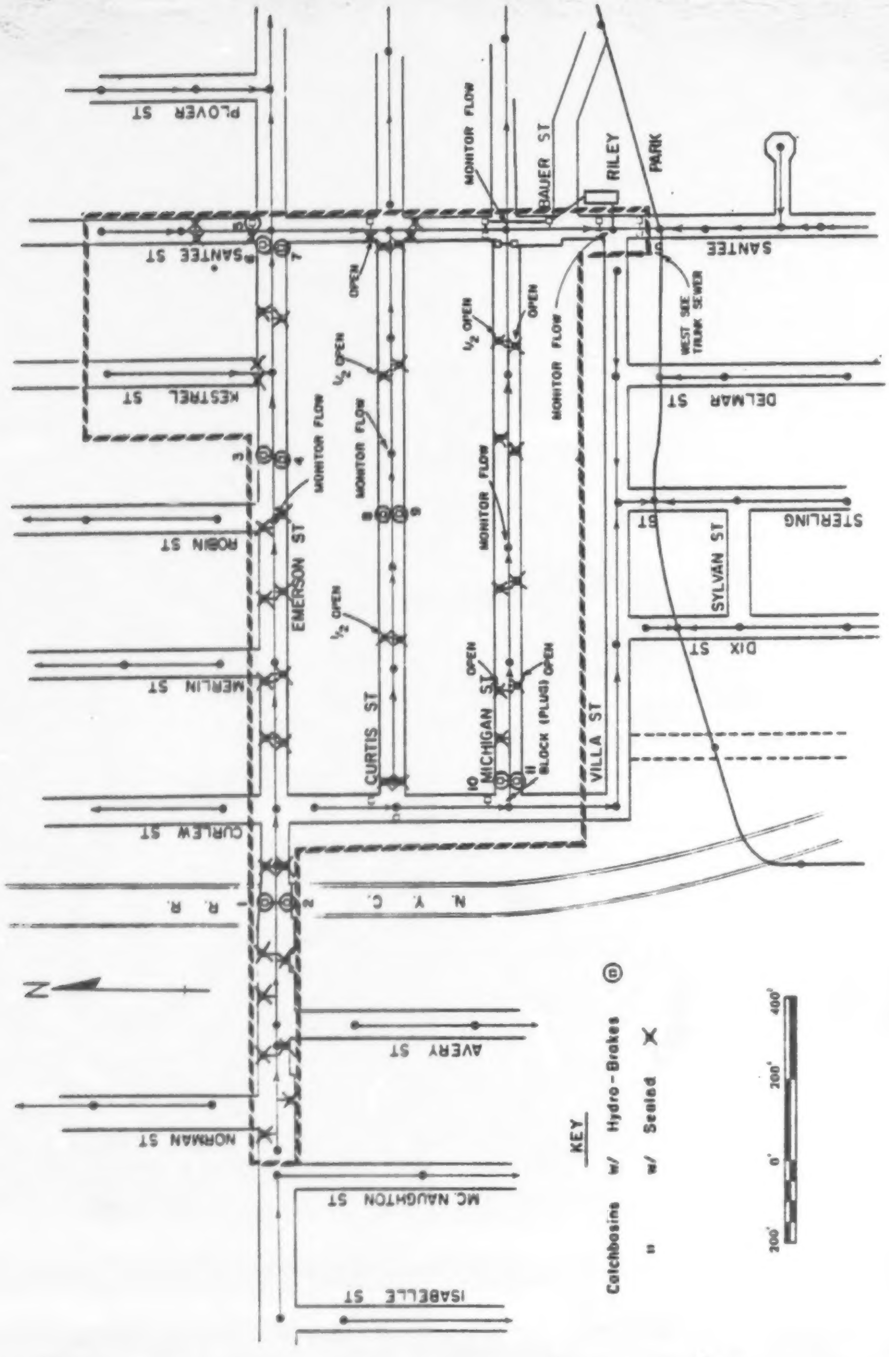

PLOVER ST
SANTEE ST
SANTEE
KESTREL ST
ROBIN ST
MERLIN ST
CURLEW ST
N. Y. C. R. R.
AVERY ST
NORMAN ST
MC NAUGHTON ST
ISABELLE ST
EMERSON ST
CURTIS ST
MICHIGAN ST
VILLA ST
BAUER ST
RILEY PARK
DELMAR ST
STERLING ST
SYLVAN ST
DIX ST
MONITOR FLOW
OPEN
1/2 OPEN
BLOCK (PLUG) OPEN
WEST SIDE TRUNK SEWER
1
2
3
4
5
6
7
8
9
10
11
N
KEY
Catchbasins w/ Hydro-Brakes
" w/ Sealed
200'
0'
200'
400'

Figure 16. Flow Monitoring Locations - Santee Drainage Area

The flow monitoring conducted in the Santee Drainage Area during 1980 showed frequent surcharging in the 12-inch combined sewer along Emerson Street. To reduce the frequency and magnitude of surcharging in this sewer stormwater inflow had to be restricted. A reference storm with a return frequency of 2 years (60 minute duration, total rain = 0.75 inches, peak intensity = 1.5 in/hr), was predicted to produce stormwater inflow from roof leader connections on Emerson Street at an estimated rate of 1.25 cfs. When combined with the normal dry weather flow rate, estimated to be 0.07 cfs, the remaining capacity in the Emerson Street sewer was determined to be 0.50 cfs. Inflow from each of the two Hydro-Brakes on Emerson Street was therefore restricted to 0.25 cfs. Hydraulic computations for the remainder of the Santee Drainage Area showed that an inflow rate of 0.25 cfs through the remaining Hydro-Brake installations was appropriate. Since the average depth from street surface to catchbasin invert was approximately 50 inches, and since it was desirable to standardize the units selected, Hydro-Brake Standard 5-B-7 units with a discharge of 0.25 cfs at 50 inches of head were specified for each of the 11 catchbasin locations in the Santee Drainage Area.

In the spring of 1981, the necessary catchbasins were sealed and Hydro-Brakes were installed in the 11 catchbasins. Figure 16 shows the location of the sealed catchbasins and the catchbasins with Hydro-Brakes installed. Early into the monitoring program in 1981, a number of residents in the neighborhood, inconvenienced by street ponding at the ends of their driveways, opened certain catchbasins in order to prevent ponding in their areas. These catchbasins are also shown in Figure 16.

In 1981, subsequent to the sealing of catchbasins and the installation of Hydro-Brakes, flow monitoring was resumed in the same locations used during 1980.

Storm Monitoring Results

Information on existing system conditions was obtained by monitoring depths of storm flow, at the previously indicated locations, from May through September 1980. For each storm at each location, the maximum depth of flow in the sewer was plotted against the maximum 15-minute rain intensity.

In 1981 monitoring began in June, after the delivery and installation of the Hydro-Brakes, and continued through mid-August. As was done in 1980, for each storm the maximum depth of flow in the sewer was plotted against the maximum 15-minute rain intensity.

At each location, 1980 results were compared to those in 1981. Figures 17-21 present these comparisons for each of the monitoring locations. At Villa and Santee, Curtiss, and Emerson and Robin (Figures 17-19), maximum flow depths obtained in 1981 for given rainfall intensities were generally lower than those observed in 1980. At Emerson and Robin, a 12-inch sewer, although sewer flows were generally reduced as a result of the study, surcharge conditions during most rainfall events still persisted.

At Michigan (Figure 20) and Curtiss and Santee (Figure 21) no improvement in 1981 data over 1980 data was seen. These results may be attributed primarily to the open catchbasins, shown in Figure 16, near these locations.

It is encouraging to note, that at Villa and Santee (Figure 17), downstream of each of the other monitoring locations, flows in 1981 were lower than those in 1980. Thus, although the study may not have shown consistent improvements in each of the upstream sewer sections, the combined effect was a reduction in peak runoffs from the drainage area as a whole.

Follow-Up Homeowner Survey

During the last month of the study, a follow-up complaint analysis was conducted. This survey concentrated on those homeowners who indicated basement flooding problems before the start of the study and on

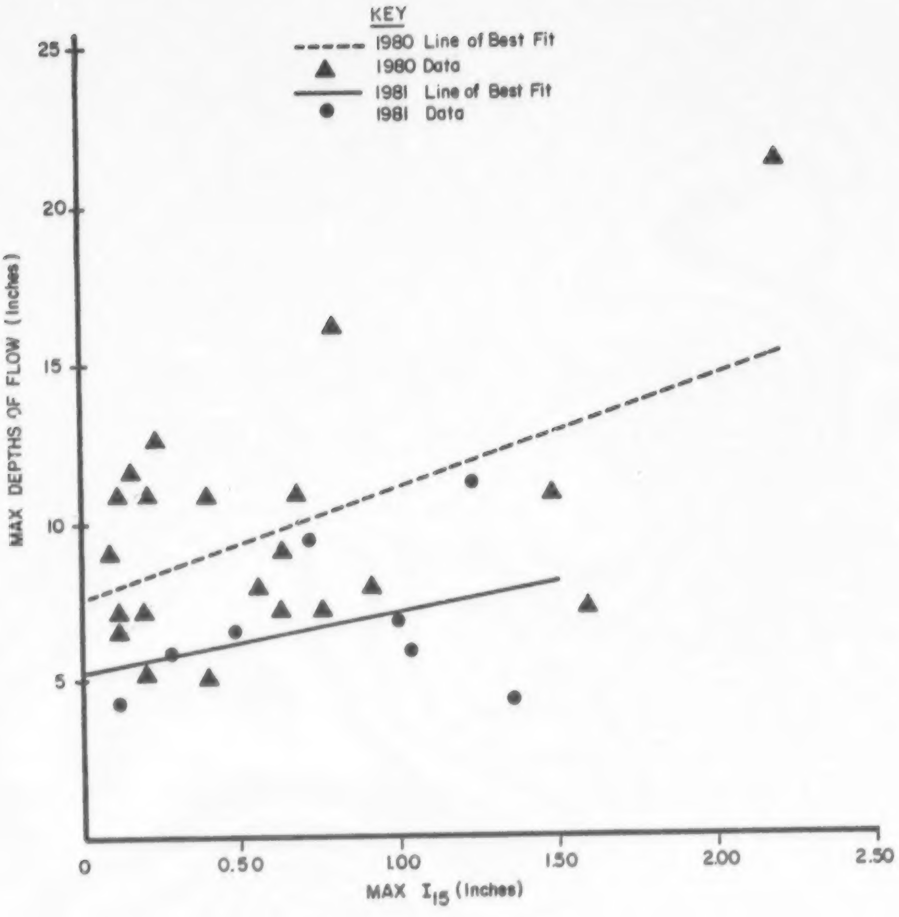


Figure 17. Monitoring Results - Villa & Santee Streets

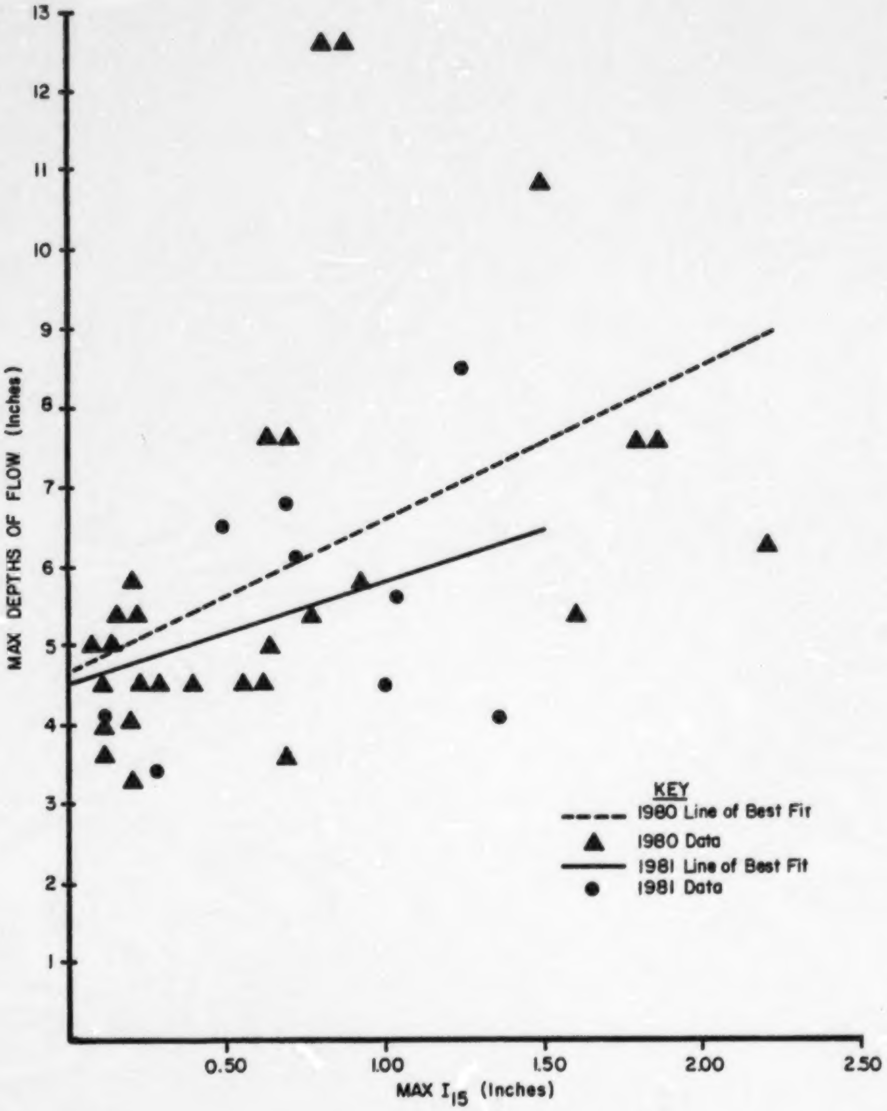


Figure 18. Monitoring Results - Curtiss Street

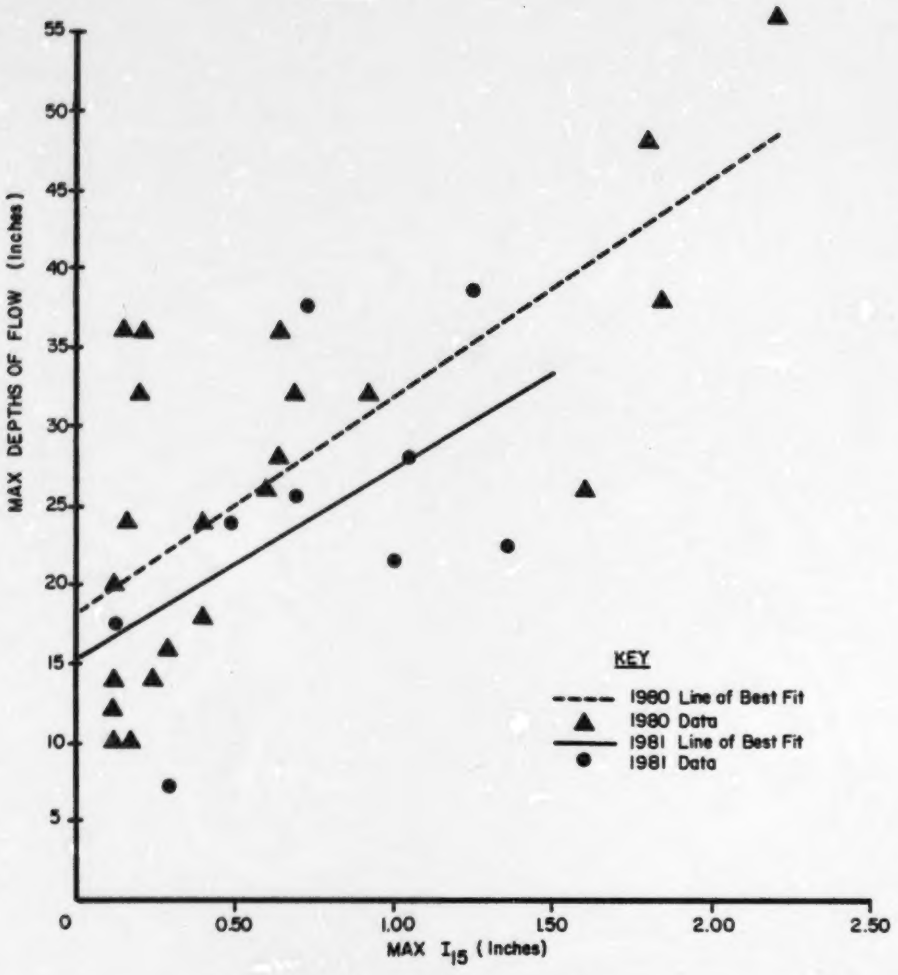


Figure 19. Monitoring Results - Emerson & Robin Streets

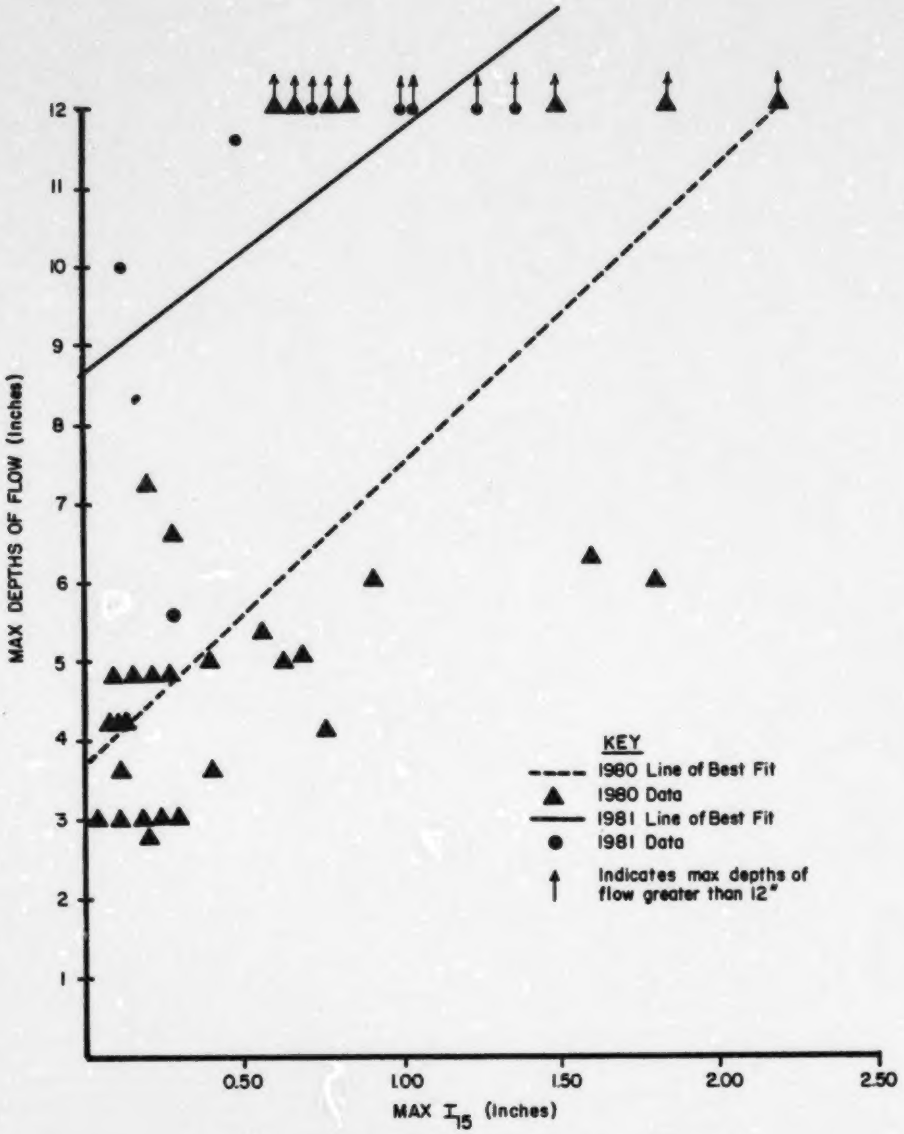


Figure 20. Monitoring Results - Michigan Street

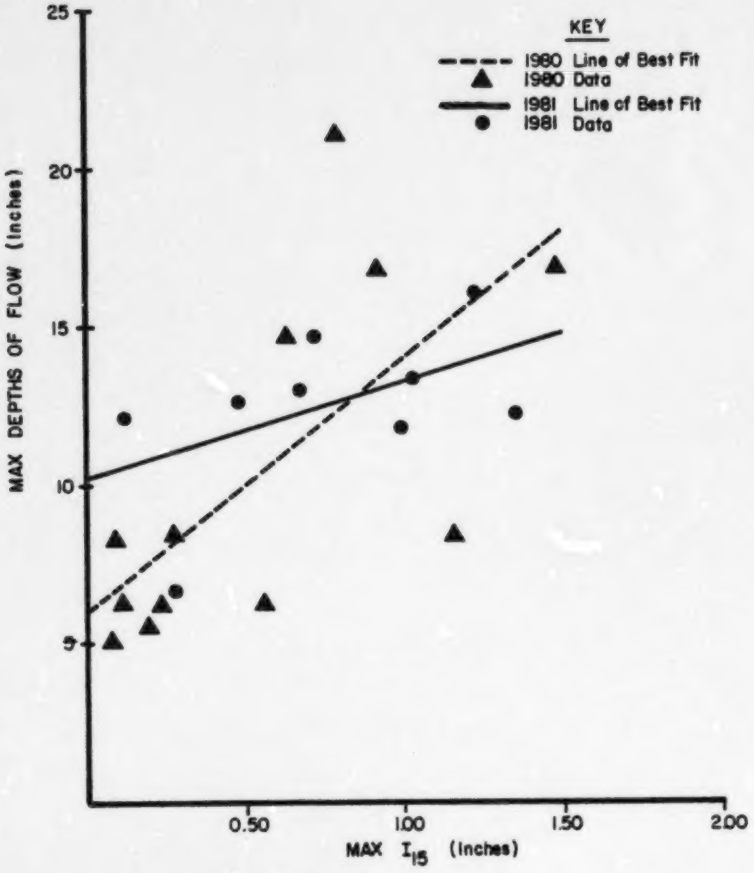


Figure 21. Monitoring Results - Curtiss & Santee Streets

those homeowners closest to the larger street ponding locations. The results of the survey were mixed, with some howeowners noticing definite improvements and others indicating no change in the frequency of basement flooding. It was therefore difficult to show a definite correlation between the level of sewer flow and the extent of basement flooding. The inconsistent results may be primarily attributed to the inability to isolate stormwater runoff from roof leaders connected to individual house laterals. The catchbasins opened by neighborhood residents inconvenienced by street ponding, may further explain the inconsistent results obtained.

Operation and Maintenance

In preparation for the monitoring program in 1980, each catchbasin in the Santee Drainage Area was cleaned. Throughout the 1980 monitoring period, only minor amounts of debris accumulated in each catchbasin. In the spring of 1981, prior to the sealing of catchbasins and the installation of Hydro-Brakes, the catchbasins were again cleaned. During the 1981 monitoring period, only minor amounts of debris accumulated in the catchbasins. This accumulation of debris did not interfere with the normal operation of the Hydro-Brakes. Larger pieces of debris, however, as at the off-line storage tank, may render the Hydro-Brakes ineffective. In order to ensure the normal operation of the Hydro-Brakes, it may be good practice to check each unit on a regular basis, especially following major storms. The catchbasins themselves, should be cleaned at least once every other year.

Installation Costs

The costs incurred in developing the inlet control system for the catchbasin study described above are the following:

Labor	$ 765	
12 Hydro-Brake Units (5-B-7) @ $600/ea.	7,200	
	$7,965	(ENR = 3510)

The costs of this alternative, about $230 per acre, are very favorable when compared to the conventional alternative - sewer separation, at approximately $42,000 per acre, as estimated in the 1978 Needs Survey (ENR = 3510).

CSO REDUCTIONS

By attenuating peak stormwater runoff, sewer surcharging and combined sewer overflow can be reduced. Both methods demonstrated in this study reduced the rate of inflow into the combined sewer system. These reduced inflows can result in reducing the frequency and magnitude of surcharging in the immediate localized tributary drainage area, and in the reduced frequency and volume of CSO further downstream in the combined sewer system.

At the off-line storage tank facility, peak discharge rates and total volume of flow during peak runoff periods were reduced. The peak discharge rate during the storm of May 11, 1981, was reduced by 75% and the total volume of flow discharged to the sewers during the peak runoff period was reduced by 60%. These types of reductions tend to reduce overflow from the combined sewer system. Since peak stormwater flows, especially during a first-flush, are generally associated with higher concentrations of pollutants, any reduction in peak discharge rates and resulting overflows may show significant improvements in pollution control. Although the off-line storage demonstration was conducted over a small drainage area, similar results would be expected using properly sized facilities with larger tributary drainage areas.

The mixed results obtained as part of the catchbasin study and confirmed in the follow-up homeowner survey can be attributable in part to the indeterminate and uncontrolled amount of stormwater runoff from roof-leaders connected directly to the combined sewer system. Due to the resulting surface ponding, many homeowners did not perceive the Hydro-Brakes to be an effective solution to their flooding problem. In order to change this perception and to eventually gain acceptance of future Hydro-

Brake implementations, it may be necessary to educate neighborhood residents on the concept of inlet control through the use of Hydro-Brakes. Hydro-Brakes are able to reduce sewer flow only at the expense of increased surface ponding. The catchbasin study, in some cases, did show reduced levels of sewer flow and surcharging. It is felt that this will subsequently result in the reduced occurrence of overflow from the combined sewer system.

SUMMARY AND CONCLUSIONS

Two different methods to reduce the rate of inflow into the combined sewer system were evaluated as a part of this project. The concept of off-line storage in conjunction with Hydro-Brake controlled discharge, serves to regulate downstream sewer flows after stormwater runoff has entered the collection system. In contrast, the surface/street ponding concept with Hydro-Brake controlled inflows, serves to regulate the rate of stormwater runoff before it enters the collection system.

Conclusions developed as a result of the off-line storage evaluations are presented below:

1. The Hydro-Brake regulator field performance curve agreed closely with the performance curve supplied by the Hydro Storm Sewage Corporation. The field unit indicated flowrates approximately 6 percent higher than the design curve at 50 inches of hydraulic head.

2. Although it performed reasonably well through a number of storms, during one period of time the Hydro-Brake was rendered ineffective by debris present in normal stormwater runoff.

3. During the period when the Hydro-Brake was rendered ineffective by debris, it failed to offer any improvement in flow restriction over a simple orifice of the same diameter.

4. Compared to an equally sized orifice, the Hydro-Brake passed less flow at given hydraulic heads when operating as designed (i.e. with flow not impeded by debris).

5. The equation of discharge obtained for the Hydro-Brake Standard 5-B-7 regulator with a 3.5-inch diameter outlet orifice was as follows:

$$Q = 0.1623\ h^{0.3290}$$

where Q = Discharge in cfs
h = Hydraulic head in feet

6. Used in conjunction with off-line storage, the Hydro-Brake regulator effectively reduced peak stormwater runoff rates into the combined sewer system by as much as 78 percent.

7. Utilization of Hydro-Brakes to reduce inflow into combined sewer systems can result in a reduction in the frequency and magnitude of combined sewer overflows. In localized drainage areas, sewer surcharging can be reduced at the expense of additional surface ponding.

Conclusions developed as a result of the catchbasin control evaluations are presented below:

1. The combination of surface/street ponding and Hydro-Brake regulated inflow to the combined sewer system may not result in significant impacts in the immediate localized tributary area. However, impacts may be felt further downstream as the combination did reduce peak runoffs from the drainage area as a whole.

2. In drainage areas where roof leaders are connected directly to house laterals, the effectiveness of restricting inflow from street runoff through use of catchbasin inlet control devices is reduced, since the fraction of runoff from roofs is not controllable by the catchbasin inlet control devices.

3. Even though the hydraulic grade line of the collection system was reduced by means of inlet control devices, the perception of homowners in the demonstration area failed to support significant improvements. The existance of surface ponding and problems unrelated to collection system conveyance capacity contributed to this perception.

In general, it should be noted that the implementation of the Hydro-Brake as a feasible static control device is significantly limited by the present capacity of the supplier to deliver units and provide field installation assistance. (Supplier now claims that delivery problems have been corrected.)

RECOMMENDATIONS

1. The design of the Hydro-Brake should be reviewed to develop modifications which would minimize the impact of stormwater debris on the optimal operation of the unit.

2. Use of the Hydro-Brake should be evaluated in conjunction with surface retention basins. These results should be compared to those obtained from the Hydro-Brake's use with off-line storage, particularly on a cost-benefit basis.

3. Further studies on the effectiveness of Hydro-Brakes in reducing peak stormwater flows and the frequency of basement flooding, should be conducted by EPA at other locations, in drainage areas where roof leaders are not connected to house laterals.